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AN EXPERIMENTAL STUDY OF THE LOAD-CARRYING CAPACITY OF STEEL ROLLERS

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University of Illinois
Urbana, Illinois 61801

By
MARSHALL HOLT
B.S., University of Illinois, 1927

THESIS

Submitted in Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Civil Engineering
in the Graduate School of the
University of Illinois, 1929

URBANA, ILLINOIS

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TABLE OF CONTENTS.

I. INTRODUCTION — Page

1. Foreword - - - - - - - - - 1
2. Objects - - - - - - - - - 4
3. Scope - - - - - - - - - - 4
4. Acknowledgments - - - - - - 5
5. Definitions and Explanations. - - - 5

PART I. ROLLING TESTS OF SMALL ROLLERS.

II. RESUME OF FORMER TESTS.

1. Introduction - - - - - - - 7
2. Experiments by Wing and Crandall - - 7
3. Experiments by Marston - - - - - 8
4. Experiments by Deslandres - - - - 8
5. Experiments by Wilson - - - - - 9
6. Experiments by Brown and Hartmann - - 12

III. DESCRIPTION OF APPARATUS AND INSTRUMENTS.

1. Apparatus for Testing Large Rollers - 14
2. Apparatus for Testing Small Rollers - 15
3. Description of Instruments - - - - 21

IV. DEVELOPMENT OF METHOD OF TESTING.

1. Description of Specimens - - - - 23
2. Measurements Made - - - - - - 23
3. Description of Test - - - - - 24
4. Conclusions for Preliminary Test - - 24

V. DESCRIPTION OF TESTS.

1. General - - - - - - - - - 32

2. Description of Specimens - - - - - - 32

3. Procedure of Testing - - - - - - - 34

VI. INTERESTING PHENOMENA

1. Surface Effects. - - - - - - - - 39

2. Flow of Material - - - - - - - - 39

VII. RESULTS.

1. Criterion for Determining Critical Load - 41

2. Individual Tests - - - - - - - - 41

3. Discussion - - - - - - - - - 96

VIII. COMPARISON WITH RESULTS OF OTHERS.

1. Discussion- - - - - - - - - - 101

IX. CONCLUSIONS.

1. Conclusions - - - - - - - - - 106

PART II. ADDITIONAL STUDIES.

I. THE EFFECT OF THE THICKNESS OF PLATE ON THE CRITICAL LOAD.

1. Foreword - - - - - - - - - - 108

2. Description of Test - - - - - - - 109

3. Results - - - - - - - - - - 111

II. ELASTIC FLOW

1. Foreword - - - - - - - - - - 127

2. Description of Test - - - - - - - 127

3. Results - - - - - - - - - - 127

III. THE CARRYING CAPACITY OF A STEEL CASTING HAVING AN H-SECTION.

1. Foreword - - - - - - - - - - 142

2. Method of Analysis - - - - - - - 142

IV. THE CARRYING CAPACITY OF STEEL CASTINGS HAVING SPECIAL SHAPES

1. Foreword - - - - - - - - - - - 156
2. Description of Test - - - - - - - - 157
3. Results - - - - - - - - - - - 159

APPENDIX.

I. PHYSICAL PROPERTIES OF MATERIAL FOR SMALL ROLLER TESTS.

LIST OF FIGURES.

1. Roller Test Under a Fixed Span - - - - - - - - - - - 2
2. Rolling Bascule Bridge - - - - - - - - - - - - - - 2
3. Diagram of Apparatus for Testing Large Rollers - - - 16
4. Photographs of Apparatus for Testing Large Rollers - - 17
5. Diagram of Apparatus for Testing Small Rollers - - - 19
6. Photographs of Apparatus for Testing Small Rollers - - 20
7. Instruments used for Measuring Strains - - - - - - - 22
8. Relation Between Load and Lateral Flow, Preliminary Test 26
9. Relation Between Load and Longitudinal Flow, Preliminary Test - - - - - - - - - - - - - - - - 26
10. Relation Between Load and Change of Diameter, Preliminary Test - - - - - - - - - - - - - - - 27
11. Relation Between Load and Spread of Roller, Preliminary Test - - - - - - - - - - - - - - - - 28
12. Diagram Showing Location of Specimens in Original Casting. - - - - - - - - - - - - - - - - - - 35
13. Diagram Showing Location of Rollers in Original Block - - - - - - - - - - - - - - - - - - - 36
14. Photographs of Specimens After Testing - - - - - - - 40
15. Flow of Annealed Steel Casting, Test H14 - - - - - - 44
16. " " " " " H10 - - - - - - 47
17. " " " " " H11 - - - - - - 51
18. " " " " " H12 - - - - - - 55
19. " " " " " H13 - - - - - - 58
20. " " " " Tests H1 & H2 - - - - - 63
21. " " " " Test H5 - - - - - - 70

22. Flow of Annealed Steel Casting, Test H3 - - - - - - - 74
23. " " " " " H3A - - - - - - 77
24. " " " " " H5A - - - - - - 81
25. " " " " " H9 - - - - - - 85
26. " " " " " H7 - - - - - - 89
27. " " " " " H7A - - - - - - 93
28. Relation Between Critical Load and Diameter - - - - - 98
29. Comparison of Proposed Design Formulas - - - - - - 103
30. Flow of Annealed Steel Casting, Test A17 - - - - - 112
31. " " " " " A18 - - - - - 113
32. " " " " " A19 - - - - - 115
33. " " " " " A20 - - - - - 117
34. " " " " " A21 - - - - - 119
35. " " " " " A22 - - - - - 121
36. " " " " " A23 - - - - - 123
37. Elastic Flow of Annealed Steel Casting, Test A17 - - 129
38. " " " " " " A18 - - 130
39. " " " " " " A19 - - 132
40. " " " " " " A20 - - 134
41. " " " " " " A21 - - 136
42. " " " " " " A22 - - 138
43. " " " " " " A23 - - 140
44. Influence Line for Stress in Web of a Steel Casting Having an H-Section - - - - - - - - - - - - - 144
45. Photographs of Set Up for Measuring Deflection of the Flange of a Steel Casting Having an H-Section - - 147
46. Influence Line for Deflection of Flange of a Steel Casting Having an H-Section - - - - - - - - - 148

47. Photographs of Huggenberger Tensometers - - - - - - - 155
48. Shape and Dimensions of Special Shaped Steel Castings - 158
49. Flow of Annealed Steel Casting, Test C31 - - - - - - 160
50. " Hylastic " " " HYL C 31 - - - - - 163
51. " Annealed " " " C41 - - - - - - 167
52. " " " " " C42 - - - - - - 169
53. " Hylastic " " " HYL C41 - - - - - 171
54. HYL C42 - - - - - 173
55. " Annealed " " " C51 - - - - - - 178
56. C52 - - - - - - 181
57. Flow of Hylastic Steel Casting, Test HYL C51 - - - - - 184
58. HYL C52 - - - - - 187
59. Unit Vertical Pressure - - - - - - C51 - - - - - - - 189
60. " " " C52 - - - - - - - 190
61. " " " HYL C51 - - - - - 191
62. " " " HYL C52 - - - - - 192
63. Flow of Annealed Steel Casting, Test C61 - - - - - - 194
64. " " " " " C62 - - - - - - 197
65. " Hylastic " " " HYL C61 - - - - - 199
66. " " " " " HYL C62 - - - - - 202
67. Unit Vertical Pressure, Tests C61 and C62 - - - - - - 204
68. " " " " HYL C61 and HYL C62 - - 205
69. Diagram Showing Location of Specimens in Original Block 208

LIST OF TABLES.

Page

1. Physical Properties of Plates for Small Roller Tests. - - - - - - - - - 37
2. Critical Loads from Tests on Small Rollers - 95
3. Comparison of Proposed Design Load with Experimentally Determined Critical Load - 105
4. Physical Properties of Plates for Thick Plate Tests - - - - - - - - - 110
5. Critical Loads from Tests of Thick Plates - 125
6. Computations for Stresses in the Web of a Steel Casting Having an H-Section - - - 155a
7. Physical Properties of Rollers for Small Roller Tests - - - - - - - - - 207
8. Physical Properties of Plates for Small Roller Tests - - - - - - - - - 209

I. INTRODUCTION.

I. INTRODUCTION.

1. Foreword. Some means should be provided to permit the end of a stiff structure to move, thereby relieving the excessive thrust which would otherwise develop when the structure expanded due to a change in temperature or stress. In the practice of bridge engineering, one end of the structure is placed on a nest of rollers which allows free longitudinal expansion of the bridge. This use of rollers is illustrated by the diagram of Figure 1.

In the rolling bascule bridge, the leaf extending across the channel is continued shoreward in the form of a circular segment. The structure is counterweighted so the center of gravity of the entire mass is at the center of the segment. As the bridge opens, it rolls shoreward on the cylindrical surface which bears on a plate girder paved with steel sole plates. The construction and action of a rolling lift bridge are shown in Figure 2.

Small rollers as used in expansion nests seem to function very well under the stresses for which they are designed, but there is a possibility of present practice being too conservative. There have been some costly failures of the sole plates of bascule bridges. Notable among these are the Causeway Bridge at Galveston, Texas and the Cherry Street Bridge in Toledo, Ohio.

There are very few experimental data available giving the bearing value of rollers. A mathematical solution of the problem would be very complicated and would require experimental verification as well as the determination of certain empirical constants. For these reasons this experimental investigation has been undertaken.

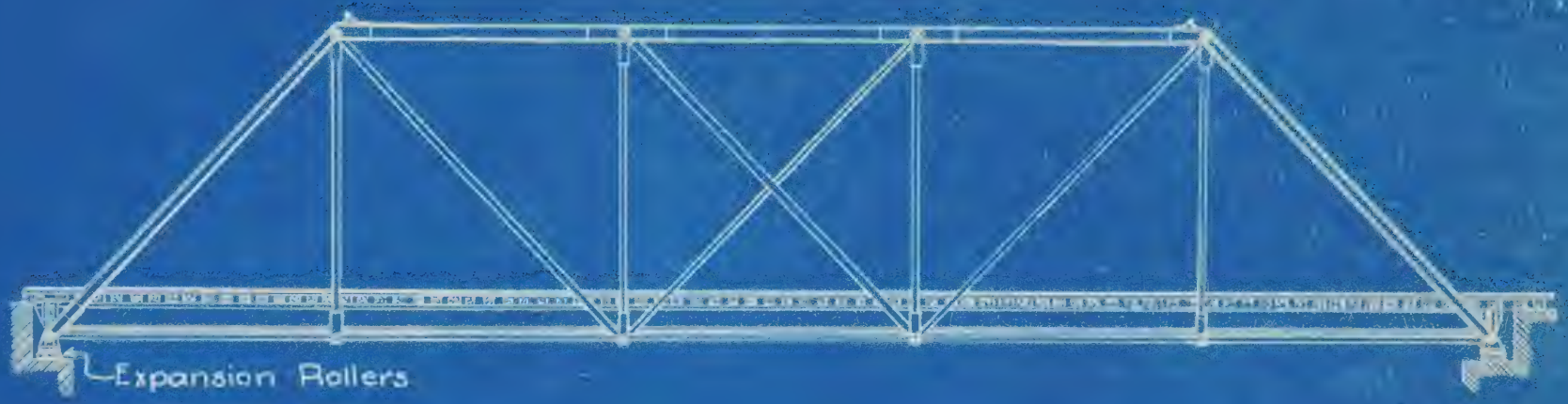


Fig. 1

Roller Nest Under a Fixed Span

2. Objects. The objects of this investigation were:

a. To develop a method of testing small rollers.

b. To obtain data upon which to base the design of small rollers.

c. To correlate the work that had been done on large and small rollers.

3. Scope. The tests for the bearing value were made on rollers varying in diameter from 2 inches to 116 inches. The only variable studied was the diameter of roller. The cylinders less than 24 in. in diameter and all the bearing plates were cut from a single medium grade steel casting and received the same heat treatment. The segments for the cylinders larger than 24 in. in diameter were cut from a casting from the same heat as the other and received similar heat treatment. The plates were all 1½ inches thick and 4 inches wide. The effect of rolling on the hardness of the material as indicated by the Brinell hardness test was studied. The strength of the material was determined by tension tests.

A separate study was made on the effect of the depth of the plate upon the bearing value. The block was an annealed steel casting of medium grade. The depth of plate varied from 8½ inches to 1-3/8 inch. The roller was 116 inches in diameter.

A study was made of the elastic flow of a plate in an attempt to develop a means of determining the critical load from the elastic flow. The flow was measured in the direction of and normal to the plane of rolling.

An analytical study was made to determine the carrying capacity of steel castings having an H-section.

Rolling tests were made on steel castings having a V-shaped top flange, with and without stiffeners, also on castings having rectangular sections. Each shape was made of two materials, carbon steel casting and a high manganese steel casting sold under the trade name of Hylastic Steel. The diameter of the roller was 236 inches.

4. Acknowledgments. The experimental work of this thesis was performed as a part of one of the projects of the Engineering Experiment Station of the University of Illinois of which Dean M.S. Ketchum is the Director and in the Department of Civil Engineering of which Professor N.C. Huntington is the Head.

The writer is very grateful to Professor W.W. Wilson, under whose supervision the testing was done, for his encouragement and many helpful suggestions. The work of Mr. W.T. Pope, machinist for the Structural Laboratory, in machining and finishing the specimens is appreciated, also his useful suggestions. The writer is indebted to Mr. Ralph Kluge, Graduate Research Assistant in the Engineering Experiment Station, for a great amount of help in performing the tests. The heat treatment of the specimens was done under the supervision of Mr. W.T. Lanham, Superintendent of the Forge Laboratory, to whom the writer is grateful. Mr. James Hardesty and Dr. H.W. Westergaard gave valuable assistance with Part II.

5. Definitions and Explanations. The range of the diameter of rollers covered by this thesis is quite wide. The term large roller shall be applied to those whose diameter is greater than 24 inches. The term small roller shall be applied to those whose diameter is less than 24 inches. This distinction is made because

the method of testing of the two groups is different, and not because of any difference in their action.

A flow of metal accompanies the rolling of a plate under a loaded cylinder if the load is great enough to produce a stress greater than the elastic limit of the material. The metal flows in all directions in the horizontal plane. The flow in the direction of the plane of rolling is termed the longitudinal flow. This is also the direction of the long side of the plate.

The flow normal to the plane of rolling or in the direction of the axis of the roller is termed lateral flow. This is also the direction of the short side of the plate.

The flow of metal in the roller was measured in only one direction. That was in the direction of the axis of the roller and adjacent to the line where lateral flow was measured in the plate. The flow of metal in the roller is called the spread of roller. It may also be defined as the change in length of the roller.

Curves showing the relation between load and deformation are given for each test. In some cases the relation is very nearly constant, then suddenly increases. In other cases the relation between flow and load is given by a curve with no definite break. The load at which the break in the curve occurs or at which the flow becomes excessive is termed the critical load or the load producing failure. The method of determining the critical load from the curves is explained in Section VII paragraph 1.

PART I.

ROLLING TESTS OF SMALL ROLLERS.

II. RESUME OF FORMER TESTS.

PART I. ROLLING TESTS.

II. RESUME OF FORMER TESTS.

1. Introduction. The material in this section has been taken largely from the thesis of Mr. W.K. Brown and Mr. K.O. Hartmann, An Experimental Study of Cylinders Bearing on Plane Surfaces, 1927.

The work of mathematical analysts leads to formulae which are complicated and a discussion of which is beyond the scope of this thesis.

Of the experimental work on rollers, only those tests of interest in this thesis will be presented.

2. Experiments by Wing and Crandall. In 1887, "Professor Crandall, assisted by Mr. Wing, conducted a series of tests to determine the wearing qualities and life of rollers for various loads and materials. The apparatus for testing consisted of 3 horisontal plates separated by 3 parallel rollers, one above and two below the middle plate. The load was distributed equally between the two lower rollers. The middle plate was moved back and forth about 3/4 of an inch by a mechanical attachment. The results of the tests showed that wearing of the surface was accompanied by a gradual rusting and blackening of the material, a black dust forming as the wearing increased. Flow of metal occurred at the sides of the rollers and around the edge of contact area on the base, at a load of 3260 pounds per inch of length on a steel roller 2 inches in diameter.

3. Experiments by Marston. "Anston Marston first began his study of small rollers at Cornell University in 1887. His first work consisted in using polarized light to study the stress distribution in optical glass rollers and plates. Tests were made at several loads, his results checking closely the intensities of the principal stresses as given by formulae based on the equations of elasticity.

"Later, in 1893, Marston continued his investigation at Iowa State College to determine the elastic limit load for rollers bearing on plane surfaces. Rollers having diameters of 1, 2, 3, 4, 6, 10, 12, 14 and 16 inches and 1 inch wide were tested upon bases 6 inches square and 0.9 inches thick. All rollers and bases were cut from the same plate of mild steel, bearing surfaces being highly polished by hand. The procedure of these tests was to apply static loads by increments, examining the surfaces carefully following each load to detect any set that might have occurred. Set was detected by holding the plate and roller to a light in a favorable position. No means of measuring this indentation was employed. Marston found that the smallest load producing a detectable set, thus determined, varied directly as the diameter and was equal to 880D, where the load is in pounds per linear inch of cylinder and D is the diameter in inches.

4. Experiments by Deslandres. "M.H. Deslandres tested three rollers bearing on cast iron plates 3.15 inches thick. A cast steel roller 9.45 inches in diameter and two cast iron rollers 6.30 inches and 4.72 inches in diameter were tested, the width of

rollers and plates in all cases being 7.87 inches. Measurements were made to determine the permanent set in the surface of the cylinders and plates following the application of successive static loads. The surface of the roller and plate was divided into seven equidistant sections. The compressed diameter at the various sections was compared with the diameter making an angle of 45 degrees with that diameter. A caliper scale was used that could be read with a maximum error of .002 m.m. (0.00008 inches.) Corresponding observations were made with the same degree of accuracy upon the bases with the use of a plane tester. Deslandres' experiments showed that the permanent set was proportional to the load up to some critical load, beyond which the set increased rapidly with an increase in load. There seemed to be no easily expressed relation between the critical load and the diameter of the roller for the three tests presented.

5. Experiments by Wilson. "Professor Wilson has determined the bearing value of large rollers under two conditions of loading, namely static and rolling. The specimens for the static tests consisted of 2 blocks of matched material. The top of the lower block, or base, was a carefully finished plane surface. The lower face of the upper block, or segment, was a carefully finished cylindrical surface. The bases and segments were from 10 to 12 inches high and 10 to 16 inches long. The two blocks constituting a pair had the same width; the width for various pairs ranging from 0.87"to 10.0." A study was made of the effect of the diameter, width of specimen, type of material (whether steel casting or steel

forging), and the hardness of the material as controlled by composition or by heat treatment. The diameters for this series varied from 120 to 720 inches.

"The results of numerous tests upon different materials show that a formula for the load that produces set is of the form $P = A + kD$, where P is the load in pounds per linear inch of cylinder, D is the diameter of cylinder in inches, and A and K are constants for a given material. The tests indicated that for diameters of 40 to 120 inches, the height of base did not appreciably affect the load causing a yield point stress in the material; but for a diameter of 480 inches decreasing the height of base below 5 inches caused a gradual decrease in the load producing a yield point stress. The results of three series of tests upon the effect of width of segment indicated that the load producing set increased with the width of the specimens up to 6 inches, but that an increase in width above 6 inches did not materially increase that load.

"The hardness of the specimens affected the load producing set very greatly. An increase in the Brinell hardness number from 105 to 165 caused a rapid increase in the load producing set, the rate of increase being very much slower as the Brinell number increased to approximately 190. Beyond this point, the load producing set remained constant or actually decreased as the hardness of the material increased.

"The rolling test series was planned to determine if a relation exists between the load that produces set for static tests and the load that causes a progressive elongation of the plate for

rolling tests. The plates for this series were of medium grade steel, 4 inches wide, 12 inches long and varied from 1/4 to 4 in. in thickness. The segment was 4 inches wide, 16 inches long, 6 inches in depth, and of hardened nickle steel, its bottom face being ground to a perfect cylindrical surface. Diameters studied in this series varied from 65 to 476 inches.

"The results of a limited number of tests show that the load that causes a progressive elongation of plate increases as the thickness of the plate, for any given diameter. An increase in diameter for any given plate likewise causes a proportional increase in this load. The loads that produced progressive elongation of the plate for diameters of 16, 30 and 40 feet rolling on 2 inch plates checked the results of static tests on medium grade steel castings very closely."

Tests performed since 1927 were planned to study the effect of (1) thickness of plate, (2) diameter of roller, (3) kind of material, and (4) heat treatment to which the material was subjected upon the load producing progressive elongation.

All specimens were plates having solid rectangular sections 4 inches wide and 12 inches long. They varied in thickness from 1/4 inch to 4 inches. The rollers varied in diameter from 116 inches to 476 inches. Most of the plates were steel castings of medium grade but a number were hot rolled steel of structural grade and two were manganese steel castings. Most of the specimens were annealed before being tested but a few were hardened by heat treatment.

The tests indicate that the minimum load producing progressive flow increases with the diameter of the roller. The equation of the line representing the relation between longitudinal flow and load for medium grade steel castings, is $P = 25,000 + 87D$, where P is the load per inch width of plate and D the diameter of the roller in inches. The relation between lateral flow and load is represented by a line whose equation is $P = 30,000 + 97D$.

The relation between the load producing longitudinal flow and the thickness of plate can be expressed by a straight line formula but the load producing lateral flow increases, reaches a maximum and then decreases.

The material from which the specimens were made affected the critical load greatly. Even two materials supposedly alike gave quite different results.

The bearing capacity of low carbon steel can be increased by heat treatment.

The formula recommended by Professor Wilson for determining the safe loads on rollers is $P = \left(\frac{p - 13000}{13000} \right)(12000 + 80D)$, where P is the safe load in pounds per inch width of plate, D is the diameter of roller in inches and p is the yield point strength of the material in tension in pounds per square inch.

6. <u>Experiments of Brown and Hartmann.</u> Both static and rolling tests were made on rollers from 8 inches to 30 inches in diameter. The static tests were designed to study the effect of diameter and hardness of plates. All the specimens were 2 inches wide. The rolling tests were made on rollers from 4 inches to 18 inches in diameter to study the effect of diameter and the force required to

produce action. The specimens were all cut from the same block of medium grade steel casting and were 6 inches wide.

The static tests indicate that the relation between the critical load and the diameter is expressed by an equation of the form $P = A + kd$. Due to erratic results no relation was set up.

In tests where the hardness of base and cylinder were not the same, the critical load depended only on the softer material. In tests on plates of varying hardness, the critical load increased with an increase in the Brinell number to about 130, then remained about the same or decreased. This relation was also found in Professor Wilson's tests on large rollers.

The relation between the critical load and the diameter is expressed by a formula of the type $P = (A + kD)\sqrt[3]{D}$.

III. DESCRIPTION OF APPARATUS

AND INSTRUMENTS.

III. DESCRIPTION OF APPARATUS AND INSTRUMENTS.

1. Apparatus for Testing Large Rollers. The apparatus for testing large rollers was the same as that used by Professor Wilson in his study of the bearing value of rollers and is shown by diagram in Fig. 3 and by photograph in Fig. 4. It consisted of 2 main parts:

(a) A built up radius arm suspended from a roller bearing which in turn was suspended from the head of the testing machine. A segment of a cylinder of the proper radius was attached to the lower end of the arm, this being the roller to be tested. Preparatory to conducting a test, the segment was refinished by grinding with a motor-driven emery wheel. This process insured the axis of the cylinder coinciding with the axis of the roller-bearing.

(b) A movable carriage driven by an electric motor. The carriage was supported by three 6½-inch hardened steel rollers. The specimen plate rested on top of the carriage as shown in Fig. 3. A hardened steel plate resting on the bed of the testing machine provided a smooth surface for the supporting rollers to roll on.

The relation of various parts is shown in Fig. 3. The radius arm can be varied in length from 18 inches to 20 feet.

The grinding preparatory to rolling was accomplished by swinging the segment back and forth over the grinding wheel which in turn was moved across the face of the segment parallel to the axis of the roller. Many methods of mounting the wheel were

devised. One is shown in the photograph in Figure 4.

The driving mechanism consisted of an electric motor, a gear train and a crank. The speed of the crank was 30 revolutions per minute making 60 strokes of the roller per minute. The throw of the crank or travel of the roller was 8 inches.

2. Apparatus for Testing Small Rollers. The apparatus used for large rollers seemed adaptable to the study of small rollers. A few alterations were necessary. The apparatus is shown by the diagram of Fig. 5 and the photograph of Fig. 6. It consisted of 2 main parts:

(a) A built up radius arm suspended from a roller bearing which in turn was suspended from the head of the testing machine. A segment of a cylinder of the proper radius was attached to the lower end of the arm. Any convenient radius arm would serve in this apparatus. The purpose of this cylinder was to transmit the load to the movable carriage. It is desirable to have the radius fairly large in order to require a small force from the driving mechanism. In these tests the radius was 58 inches.

(b) A movable carriage driven by an electric motor. The carriage was supported on the specimen roller to be tested which in turn was supported by the specimen plate.

To secure stability, two 8 inch channels were bolted to the carriage as shown in Fig. 5. The outer ends of these channels were carried by a small roller mounted on a table which transmitted its load to the floor and not through the testing machine. The load measured by the testing machine was the load carried by the specimen

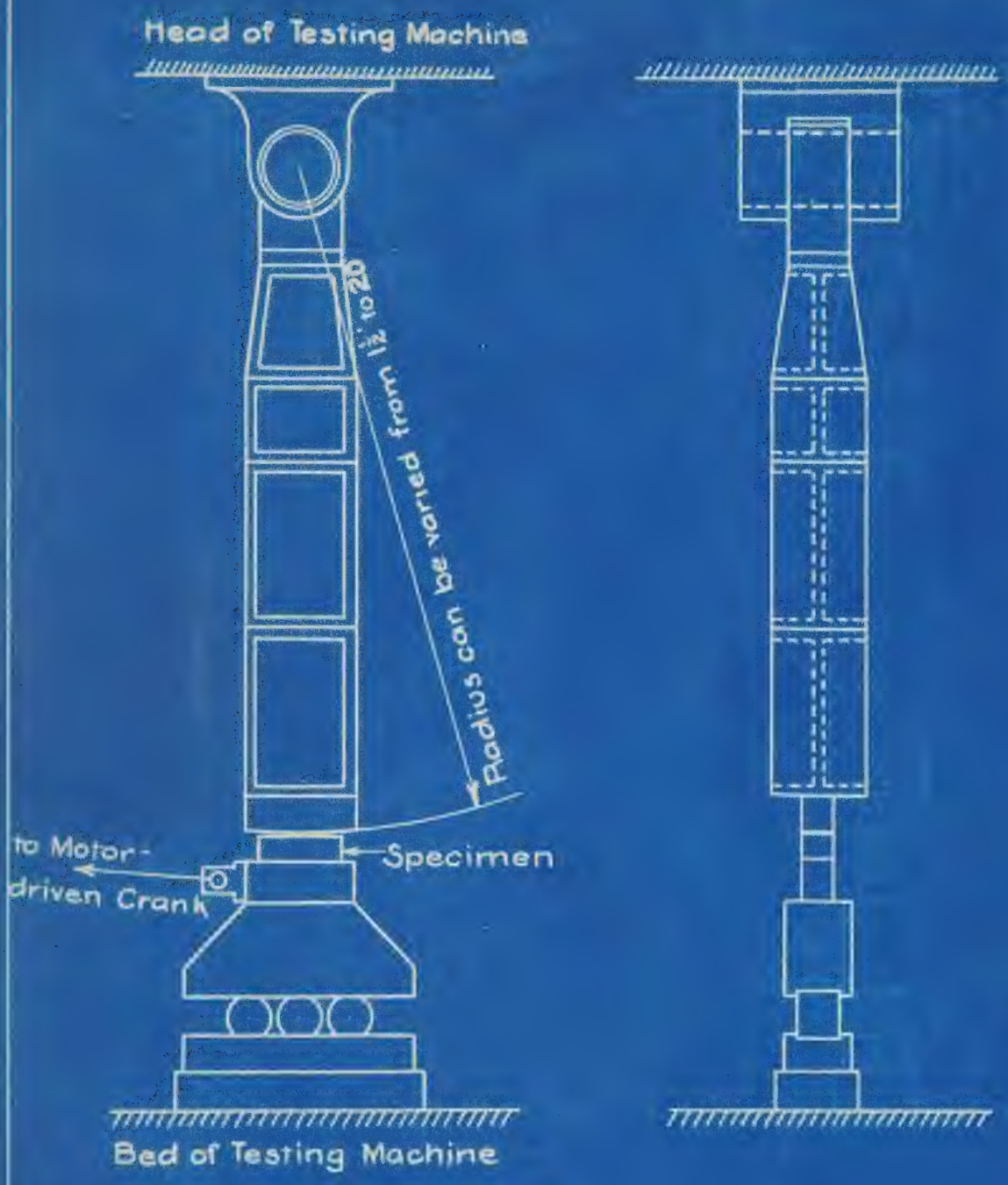
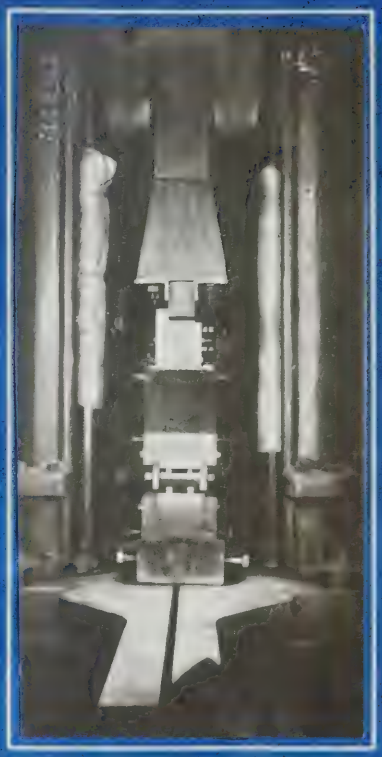


Fig. 3
Diagram of Apparatus for Testing Large Rollers

Grinding Wheel



Specimen in Place

Driving Mechanism

Fig 4
Apparatus for Testing Large Rollers

roller. It was necessary to keep the line of pressure of the testing machine between the specimen roller and the small auxilliary roller supporting the ends of the channels. Since the line of pressure remained at the center of the testing machine, it is obvious that the load on both rollers would vary during the travel of the carriage if the top of the carriage remained perfectly horizontal. In order to keep the load on the specimen roller constant, the bearing block on top of the carriage was shimmed up at one end until the load on the specimen remained constant throughout the travel of the carriage.

The driving mechanism was the same as used in the apparatus for testing large rollers.

The carriage and roller had to be lifted in order to get the plate in its place. The carriage was lifted by fastening it to the radius arm by means of hooked bolts and raising the head of the testing machine. The bottom ends of the bolts were threaded for nuts so they could be loosened during the process of rolling and tightened before the load was removed so the slack would not have to be taken up by raising the head of the machine.

The rollers larger than 8 inches in diameter were too heavy to lift by hand; so they were hooked to the carriage and raised with the head of the machine.

The arrangement of hooks is shown by the photographs of Figure 6.

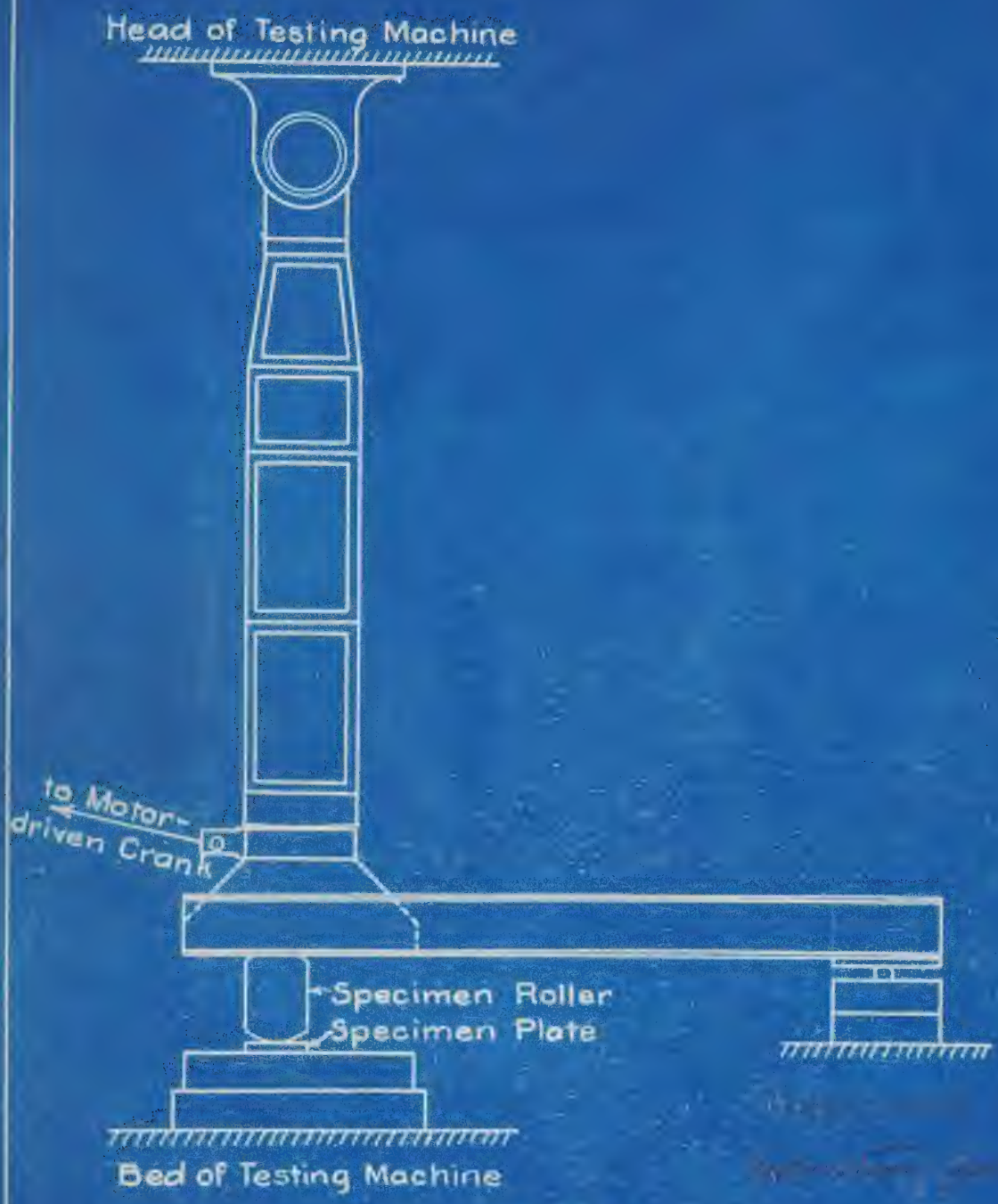
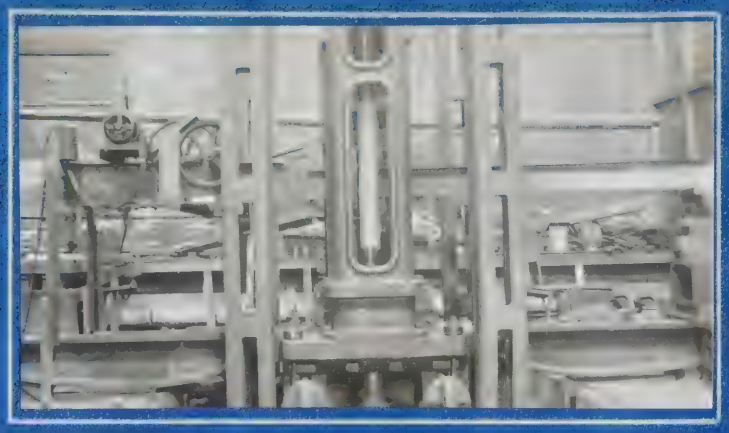


Fig. 5
Diagram of Apparatus for Testing Small Rollers



General View of Apparatus

Specimen in Place

Hooks for Raising Carriage

Fig 6.
Apparatus for Testing Small Rollers

3. Description of Instruments. The measuring instruments used during these tests are shown in Figure 7.

The micrometer is a Brown and Sharpe instrument. One division on the scale indicated 0.001 of an inch and tenths of a division were read on a vernier on the micrometer spindle.

The strain gage is of the Berry type using a 2 inch gage length. It is provided with an Ames dial graduated to thousandths of an inch movement of the plunger. The multiplication ratio is five making one division of the dial represent 0.0002 of an inch. Tenths of a division on the dial were estimated.

An instrument devised for making the measurement of elastic lateral flow of the plate is here called the yoke. It consists of a U-shaped yoke which has a pointed, adjustable screw in one leg and a micrometer dial mounted on the other. A flexible arm mounted on the leg carrying the dial is provided with a hardened steel point in line with the plunger of the dial. The points on the adjustable screw and flexible arm engage holes drilled with a number 54 drill 1/8 of an inch from the surface of the plate. The dial is of the Last Word type in which one division of the dial represents 0.0001 of an inch movement of the plunger. Divisions on the dial were estimated with an accuracy of perhaps plus or minus two tenths.

Strain-Gage
for Measuring
Longitudinal Flow

Yoke
for Measuring Elastic
Lateral Flow

Micrometer
For Measuring Lateral Flow

Fig. 7
Instruments
For Measuring Strains

IV. DEVELOPMENT OF METHOD OF TESTING.

IV. DEVELOPMENT OF METHOD OF TESTING.

1. Description of Specimens. A preliminary test was made on a roller 4½ inches in diameter bearing on a plate 1 inch by 4 inches by 8 inches. The roller was 4 inches long in the direction of its axis. Both the roller and plate were machined from steel of structural grade taken from the stock in the laboratory. The surfaces were finished with a file and emery cloth and proved with a machinist's face plate.

2. Measurements Made. Measurements were made to determine:

(a) Permanent lateral flow of the plate. The lateral flow was determined by measuring the width of the plate before and after rolling, the load being removed while the readings were taken. The difference in the width is the lateral flow of the plate in 4 inches. The unit lateral flow or flow in inches per inch of width is plotted in Fig. 8. Measurements were made 1/8 of an inch from the top and bottom and at the mid-height of the plate.

(b) Elastic lateral flow of plate. The yoke was used for measuring the elastic lateral flow. It was mounted on the plate and the dial reading observed while the roller was in motion. The difference between the readings when the roller was at the end and middle of the stroke is interpreted to be the elastic flow of the plate.

(c) Permanent longitudinal flow of the plate. The difference in strain gage readings of the unloaded plate before and after the plate had been rolled is the total longitudinal flow in 2 inches.

The unit longitudinal flow is plotted in Figure 9. Measurements were made 1/8 of an inch from the top and bottom and at the mid-height of the plate.

(d) Change in diameter of roller. The change in diameter of the roller was determined by measuring the diameter with the micrometer before and after rolling. The change of diameter is plotted in Figure 10.

(e) Spread of roller. The spread of the roller was determined by measuring the length of the roller with the micrometer in the direction of its axis before and after rolling. The unit spread of roller is plotted in Fig. 11.

3. Description of Test. After a complete set of measurements had been made, the specimens were rolled under a load of 200 LD or 3600 lb., L being the length of the roller in the direction of its axis and D the diameter in inches. Measurements were taken at the end of about 30, 60, 120, 250, 500, 1000 and 2000 strokes to determine the strains in the specimens. The load was then increased 3600 pounds and the process repeated. The test was thus continued, the load increasing by increments of 3600 pounds, up to a final load of 2000LD. The results of this test are presented in Figures 8, 9, 10 and 11.

4. Conclusions from the Preliminary Test. The following conclusions were reached:

(a) The maximum lateral flow occurred at the top of the plate, the flow at the middle and bottom being almost negligible as indicated in Figure 8a. The readings were easily duplicated and

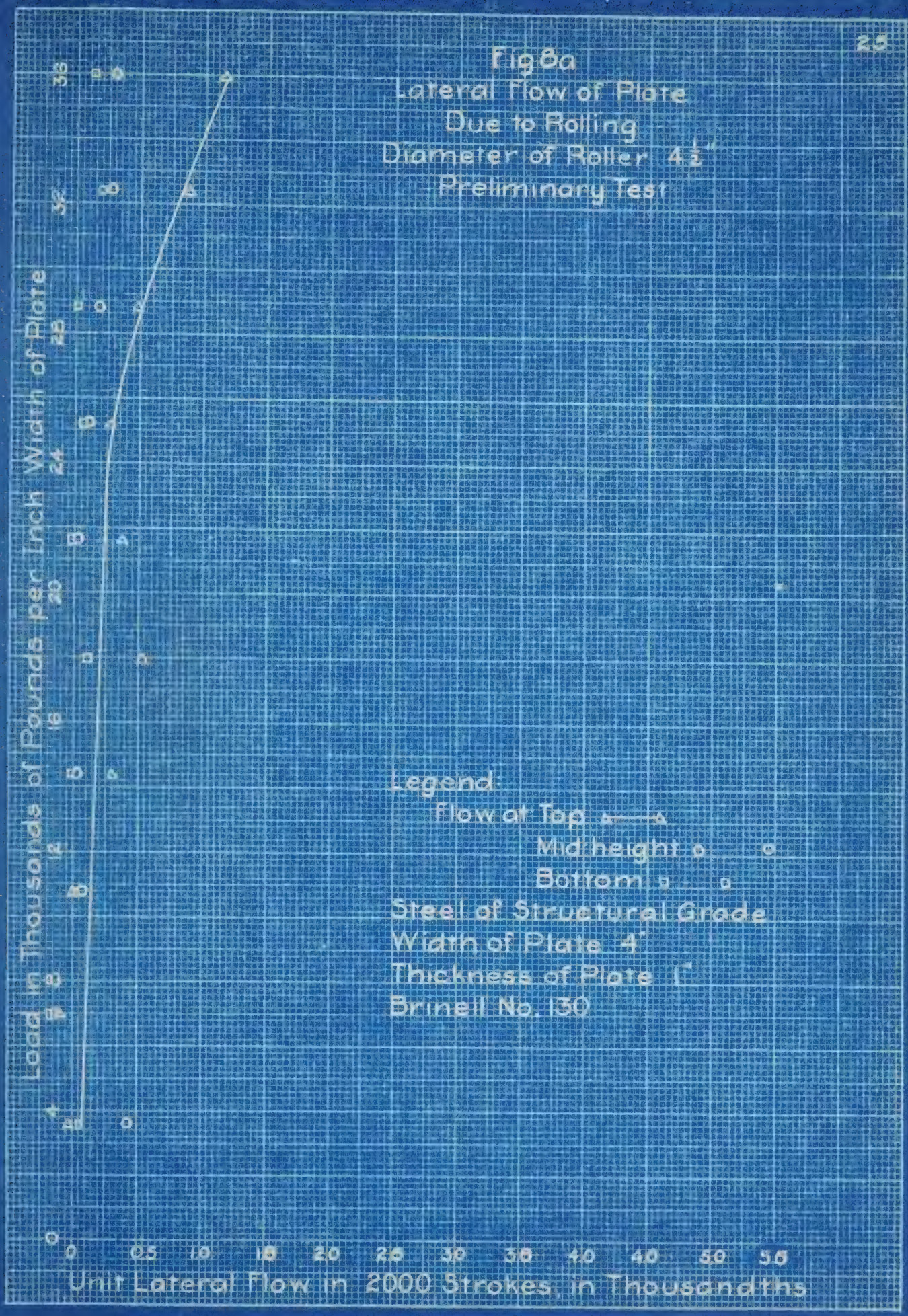


Fig 8a
Lateral Flow of Plate
Due to Rolling
Diameter of Roller 4½"
Preliminary Test
Load in Thousands of Pounds per Inch Width of Plate
Unit Lateral Flow in 2000 Strokes, in Thousandths
Legend
Flow at Top
Mid height
Bottom
Steel of Structural Grade
Width of Plate 4"
Thickness of Plate
Brinell No. 150

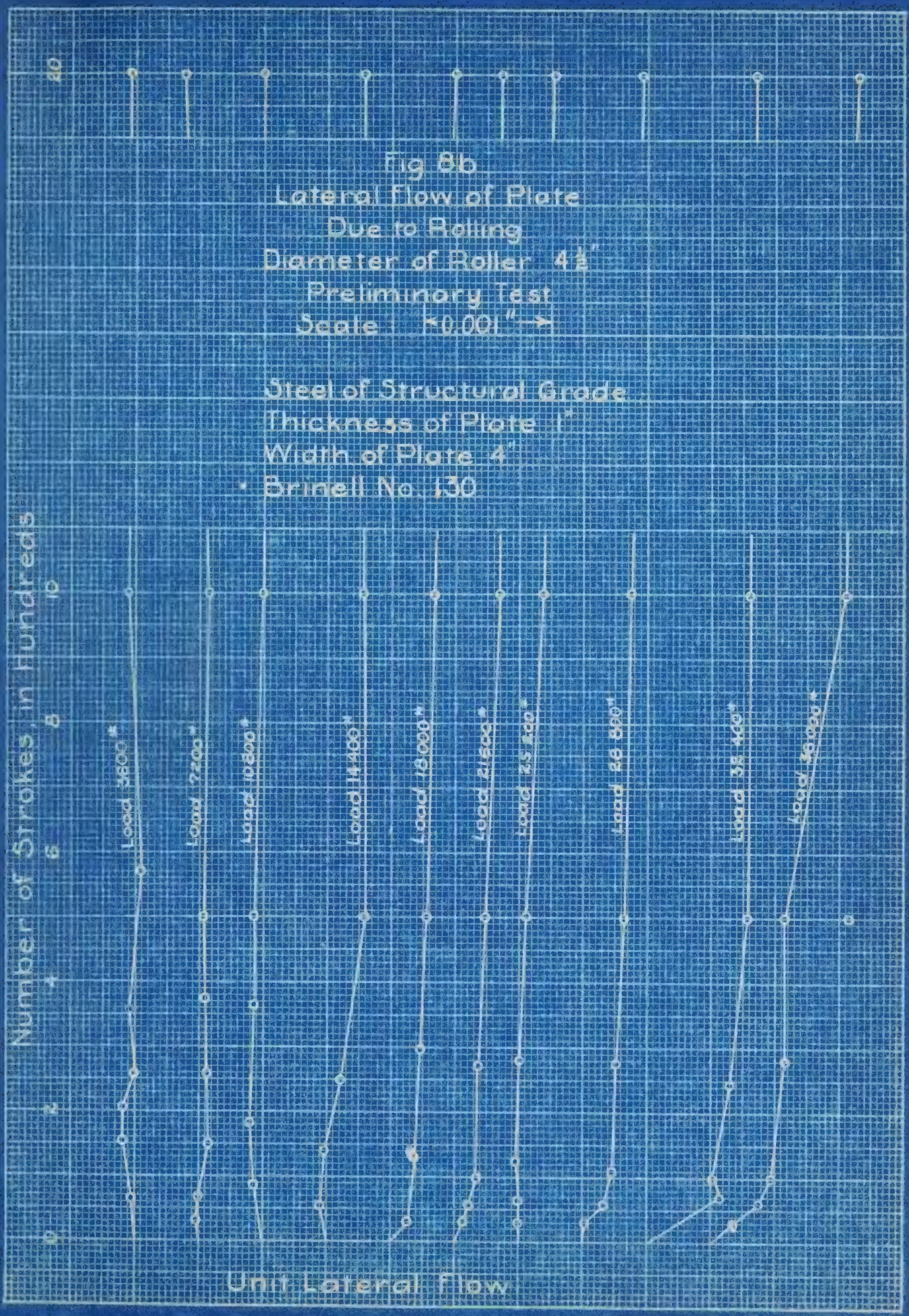


Fig 8b
Lateral Flow of Plate
Due to Rolling
Diameter of Roller 4½"
Preliminary Test
Scale 1"=0.001"
Steel of Structural Grade
Thickness of Plate 1"
Width of Plate 4"
Brinell No. 130
Number of Strokes in Hundreds
Unit Lateral Flow

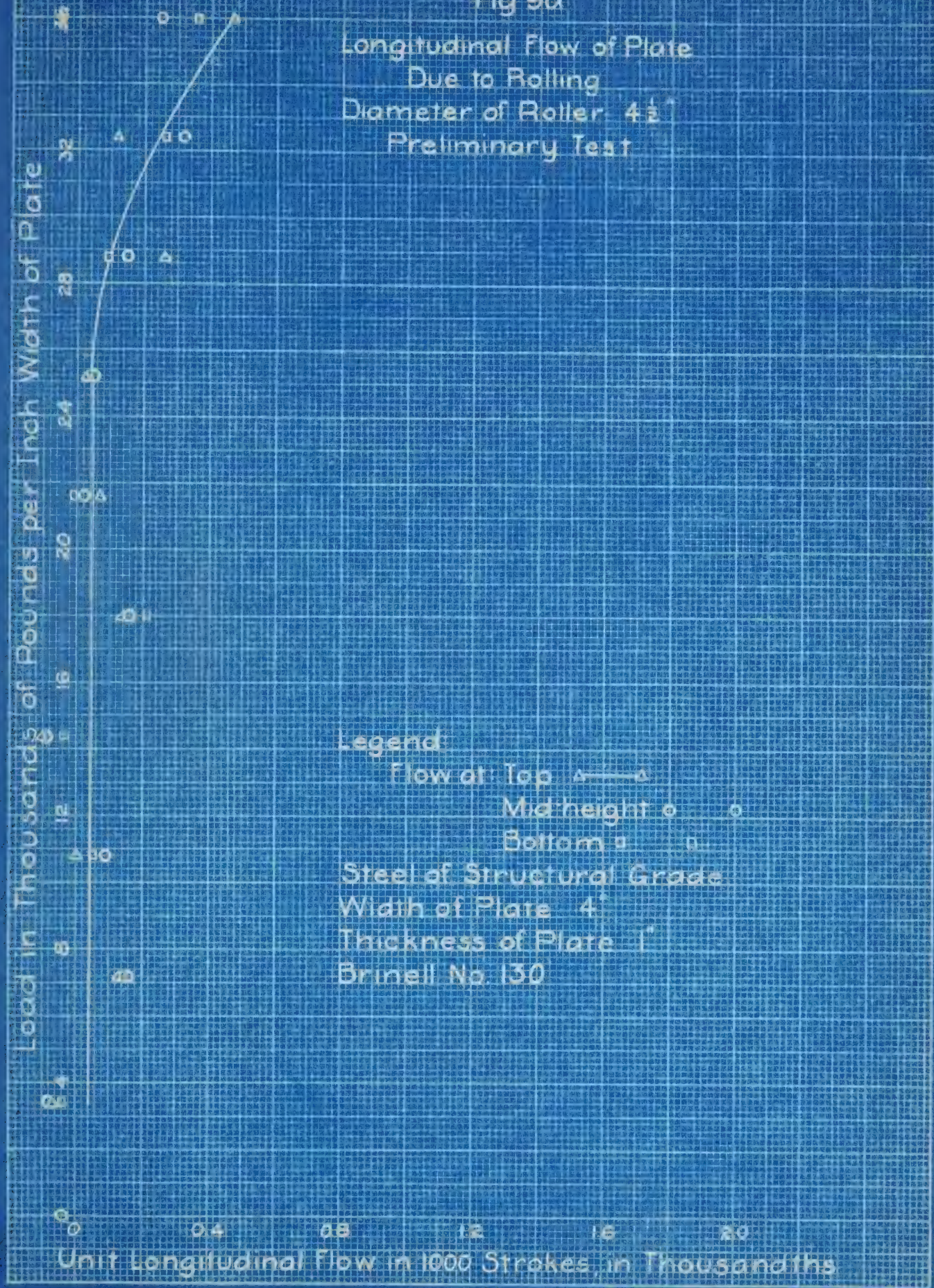


Fig 9a
Longitudinal Flow of Plate
Due to Rolling
Diameter of Roller 4½"
Preliminary Test
Load in Thousands of Pounds per Inch Width of Plate
Unit Longitudinal Flow in 1000 Strokes in Thousandths
Legend:
Flow at Top
Mid height
Bottom
Steel of Structural Grade
Width of Plate 4"
Thickness of Plate 1"
Brinell No. 130

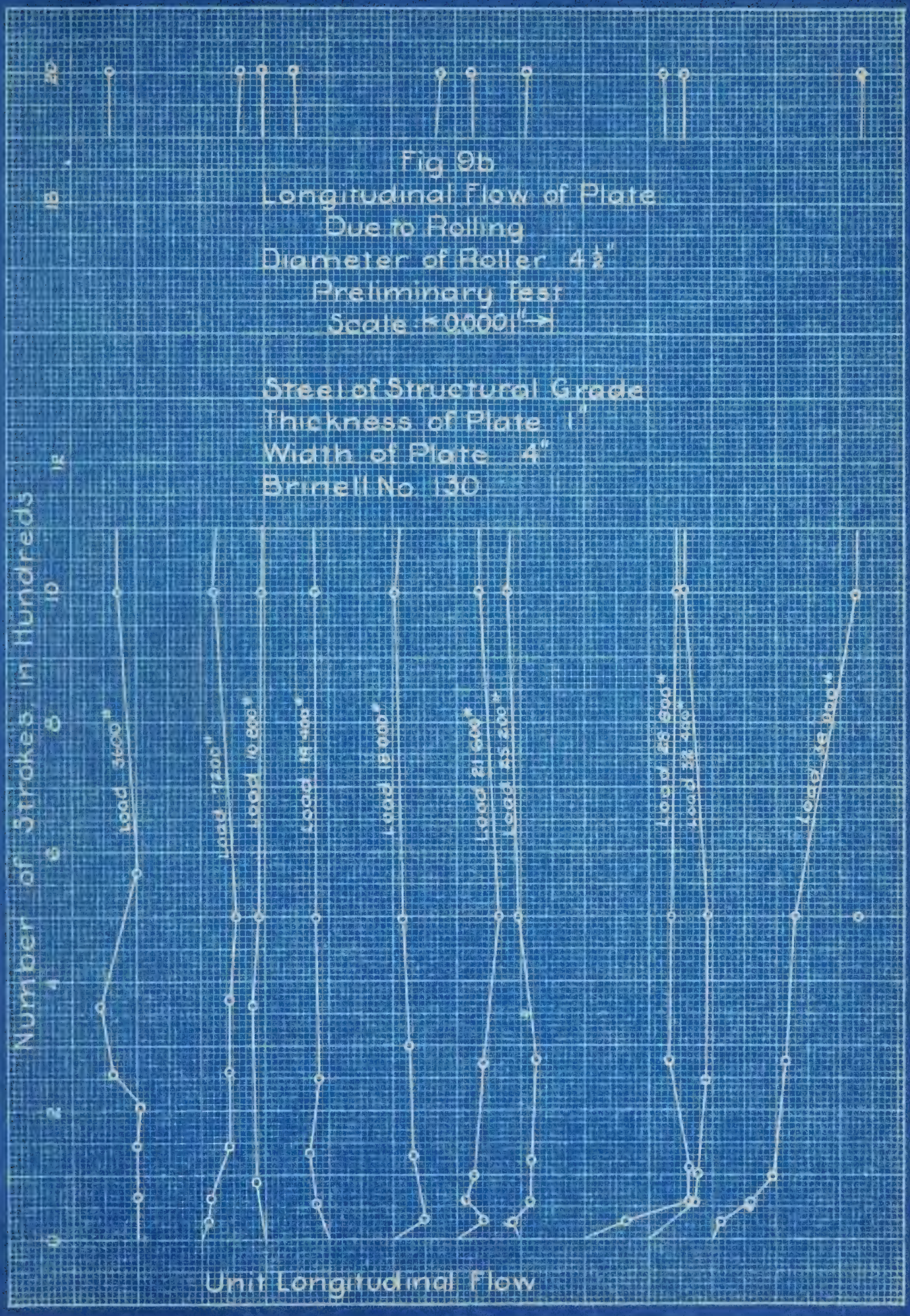


Fig 9b
Longitudinal Flow of Plate
Due to Rolling
Diameter of Roller 4½"
Preliminary Test
Scale 1:0.0001"
Steel of Structural Grade
Thickness of Plate 1"
Width of Plate 4"
Brinell No. 130
Number of Strokes in Hundreds
Unit Longitudinal Flow

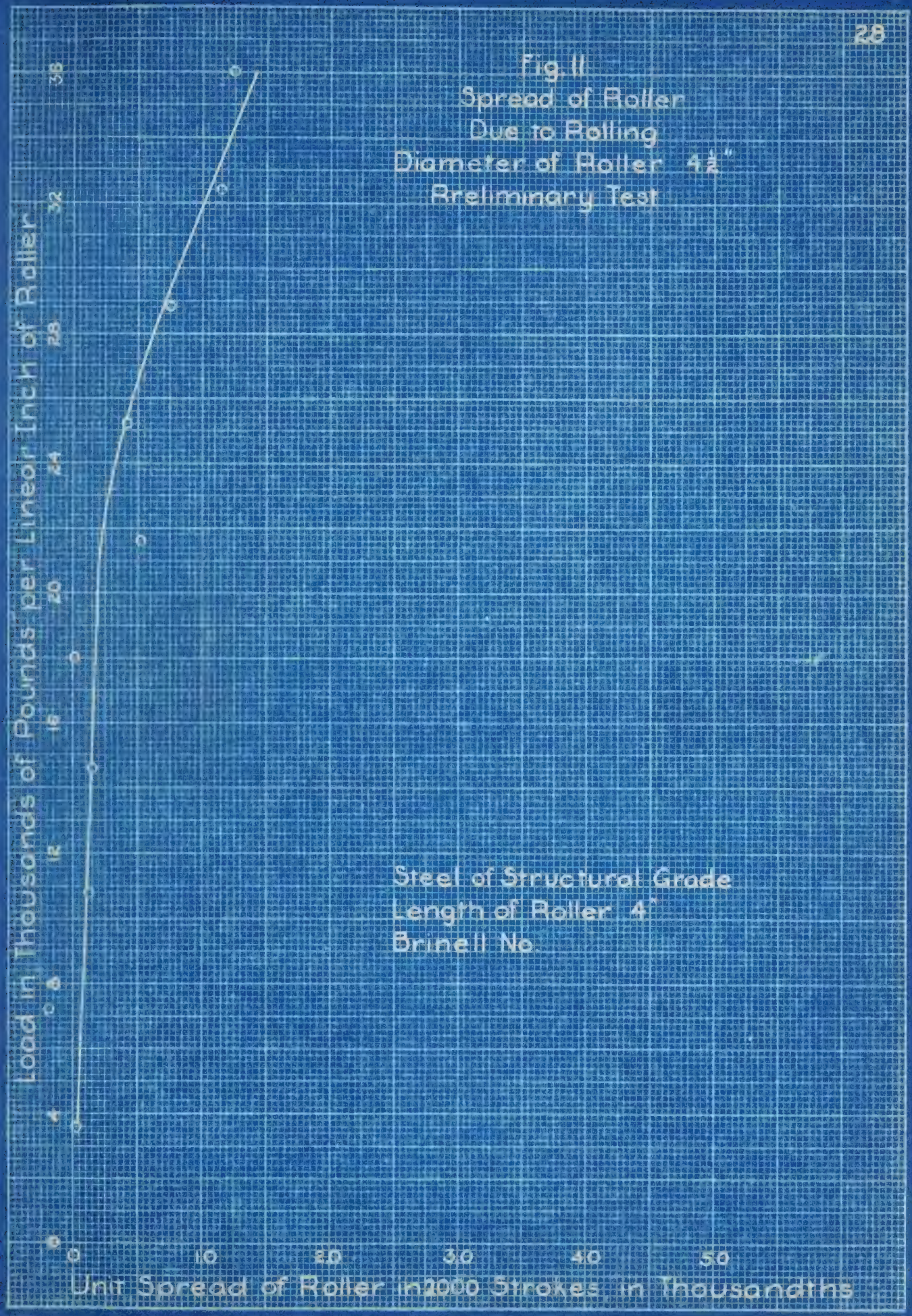


Fig. 11
Spread of Roller
Due to Rolling
Diameter of Roller 4½"
Preliminary Test
Steel of Structural Grade
Length of Roller 4"
Brinell No.
Load in Thousands of Pounds per Linear Inch of Roller
0
4
8
12
16
20
24
28
32
36
0
10
20
30
40
50
Unit Spread of Roller in 2000 Strokes in Thousandths

seemed to be a good index of the behavior of the material.

(b) The measurements for the elastic lateral flow of the plate did not prove to be of sufficient value to warrant the time required to take them, although the readings were easily duplicated.

(c) Measurements for the change in diameter were not worth taking. The readings were very difficult to make because it was impossible to place the micrometer on the same points each time as rolling obliterated any marks on the surface.

(d) The curve showing unit spread of roller is very similar to that showing unit lateral flow of plate.

(e) The flow of metal does not continue with rolling. The flow at the end of 100 strokes is about the same as at the end of 2000 strokes.

V. DESCRIPTION OF TESTS.

V. DESCRIPTION OF TESTS.

1. General. The tests constituting this investigation were performed on the same plan as the preliminary test. Each specimen was rolled a total of 1000 strokes and measurements were taken at the end of 100, 500, and 1000 strokes.

Since it was desired to tie the results of this series of tests to a series on rollers larger than 116 inches in diameter that had been performed by Professor Wilson, this series was made as nearly like Professor Wilson's series as possible. It was found in tests on large rollers that a variation in the quality of the material and thickness of plate caused a variation in the bearing value of the roller. There were in the laboratory some steel castings 4" x 12" x 36" from the same heat as the one tested by Professor Wilson. The same thickness of plate was used in the two series.

Measurements of the permanent lateral and longitudinal flow of the plate and spread of roller were thought sufficient to detect progressive flow when it occurred.

2. Description of Specimens. The casting from which the specimens of this series were cut was one of a number in the laboratory from the same heat. Some were honeycombed with blow holes but this one seemed to befree from such defects. The chemical analysis shows the following properties: C, 0.283; S, 0.043; Si, 0.046; Mn, 0.496.

Originally the casting was 4" x 12" x 36". After being cut

into two pieces, one 4" x 12" x 12" and the other 4" x 12" x 24", it was annealed by heating to a temperature of about 1450 degrees F, holding at that temperature for about six hours and cooling in the furnace, both pieces being treated at once.

All the plates and small rollers were cut from this casting. The segments for the cylinders of the large rollers were cut from plates that had been tested in a study of large rollers and were from a similar casting. Figure 12 shows the location of each plate in the original casting.

Specimens H1 to H6 inclusive were 1½" x 2" x 8", H7 and H9 were 1½" x 4" x 6" and H10 to H14 inclusive were 1½" x 4" x 12". The specimens were machined in a shaper, the rolling surfaces being finished by hand with a file and emery cloth and proved with a machinist's face plate.

In some cases where the deformation of the plate at the bottom was very small, the block was turned over, finished on the bottom and tested again. The second test is designated by an additional letter A so that H3 finished on the bottom became H3A.

The small rollers were cut from a portion of the large piece of the casting. Since the travel of the carriage was 8 inches, a full cylinder was not necessary in most cases. The block from which the rollers was turned was 4" x 8" x 24". After each individual test, the rolled portion of the roller was cut off with the hack saw. Tension test specimens were cut from the piece removed. The roller was then turned to the next smaller cylinder. Figure 13 shows the location of each roller in the block.

The physical properties of the material are given in Table 1.

They were determined for the rolled and unrolled portions of the plate. The specimens taken from the rolled portion of the plate were located ½" from the lateral centerline and the specimens from the unrolled portion were taken ¾" from the end of the plate.*

3. Procedure of Testing. The specimens were placed in the machine and centered with respect to the plane of rolling. After a load was put on the roller, thickness gages were placed between the segment and plate. If they were parallel, it was assumed the pressure was uniformly distributed across the specimen. If the gages were not parallel the bearing plate was shimmed up on one side until they were. The load on the roller was measured at the middle and ends of the stroke. If it was not constant, adjustment was made by shimming under one end of the bearing plate until it was constant.

With the apparatus in adjustment and the initial measurements made, the load was applied by the testing machine. It usually dropped several hundred or a thousand pounds with the first few strokes, so it was watched closely and brought back to the original value. After the desired number of strokes had been made, the load was removed and the specimens were measured. The load was then increased, the increment varying with the size of roller. Readings were again taken after 1000 strokes. This process was repeated, the load being increased until a considerable flow had occurred.

The Brinell tests for hardness were made on the rolled and unrolled portion of the plate and segment.

The tensile test for physical properties was made on standard

*Physical properties of rollers will be found on page 206.

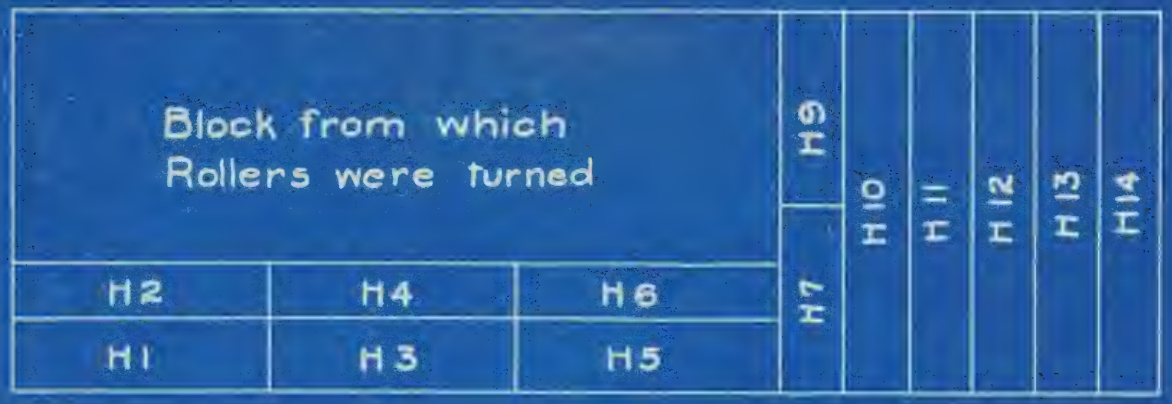


Fig. 12

Diagram Showing Location of Specimens in Original Casting.

Fig. 13
Diagram Showing Location of Rollers in Original Block

Table I

Physical Properties of Plates

Bearing Value of Small Rollers

Specimen	Before Rolling					After Rolling				
	Ultimate Strength	Yield Point	Elongation in 2 inches	Reduction of Area	Brinell Number	Ultimate Strength	Yield Point	Elongation in 2 inches	Reduction of Area	Brinell Number
H1	64,410	30,960	31.00	40.72	128	65,820	37,440	24.50	30.31	147
H2	63,142	33,050	29.75	39.81	129	64,260	34,320	26.00	34.62	147
H3					141					159
H3A	64,500	31,880	27.25	36.39	128	65,030	34,640	27.87	38.76	151
H5					118					134
H5A	64,870	32,790	31.87	46.33	130	65,160	33,410	20.81	46.30	157
H7					128					165
H7A	64,630	32,060	30.75	38.12	132	63,600	32,890	26.00	29.38	185
H9	64,660	33,600	26.50	45.41		44,730	31,680	5.37	19.69	
H10										
H11	63,950	30,800	28.25	28.97	130	64,710	35,340	22.50	26.82	139
H12	64,130	30,920	28.12	33.16	129	64,490	34,590	26.50	31.17	139
H13	64,210	30,760	27.19	38.84	125	64,180	33,160	27.12	40.76	136
H14	65,700	31,500	27.75	39.69	128	64,310	33,660	28.00	38.84	138

tensile specimens ½ inch in diameter and ¼ inches long. The yield point stress was determined by the drop of the beam. The percentage elongation was measured on a gage length of 2 inches on diametrically opposite lines. The ultimate stress is calculated as the breaking load divided by the original area.

VI. INTERPRETING PHENOMENA.

VI. INTERESTING PHENOMENA.

1. Surface Effects. At the beginning of each test, the bearing surfaces were perfectly smooth and shiny. As the heavier loads were rolled, the surfaces became covered with a sort of black dust which was easily wiped off.

2. Flow of Material. The first evidence of flow of materia was the sharpening of the corners of the plate. In most cases the flow increased until it became detectable to the touch. The photographs of Figure 14 show some cases of excessive flow. The reason for there being no noticeable flow at the top of the roller on H9 shown in the photograph is that the roller had to be kept filed down to roll between the guides on the carriage. However, the flow at the bottom of the roller is quite noticeable. In the photograph showing lateral flow of plate, the sides of the plates are curved. Before testing, the sides of the plate were straight and parallel. Dents for the Brinell Hardness test can be seen in one plate. The surface of the plate shown in the upper right photograph was perfectly smooth before testing.

Spread at Bottom of Roller

Surface of Plate After Rolling

Lateral Flow of Plate

Fig 14
Photographs of Specimens After Testing

VII. RESULTS.

VII. RESULTS.

1. Criterion for Determining Critical Load. The relations between load and flow are shown in the accompanying figures. If the load-deformation curve contains a sharp break, the load at which the break occurs is the greatest load that can be rolled without producing excessive flow and hence should govern the design of plates and rollers.

The curves showing the relation between load and lateral flow and between load and spread of roller do not contain a definite break. The critical load is, therefore, considered to have been reached when the unit flow became 0.001 inches per inch in 1000 strokes.

The curves showing the relation between load and longitudinal flow are of three general types. The first type has a definite break in the relation of load to flow as at point a Figure 20 b. The critical load is interpreted to be that at the break in the curve. Another type of curve, as shown in Figure 23 b, has a reversal of curvature. The critical load is interpreted to be that at the point of reversal indicated by the letter a. The third type of curve, as shown in Fig. 26b, has neither a sharp break nor a reversal of curvature. The curve indicates that the critical load for longitudinal flow has not been reached. Perhaps either a reversal of curvature or break in the curve would have been obtained if the test had been continued at higher loads.

2. Individual Tests. The plates used in these tests were all cut from the same steel casting after it had been annealed. All

plates were 4 inches wide and 1.5 inches thick. All plates except H14 were rolled under segments made of annealed steel castings similar in properties to the plates. The plate N14 was tested under a segment made of hardened nickel steel. Details of the various tests are given in the following paragraphs. The physical properties of the material are given in Table 1.

<u>116. In. Roller of Hardened Steel on H14.</u> The tests on large rollers with which this work is to tie in were made with hardened steel rollers. In order to determine the effect of the hardness of the roller on the bearing value of the plate, one specimen was roller under a hardened roller.

The load-deformation curves for this test are given in Figure 15.

The critical load determined by lateral flow is 34,000 pounds per inch width of plate.

The critical load determined by longitudinal flow im interpreted to be at the break in the curve and is equal to 33,000 pounds per inch width of plate.

Fig 15a
Lateral Flow of Plate
Due to Rolling
Under Hardened Steel Roller
Diameter of Roller 16"
Test H14

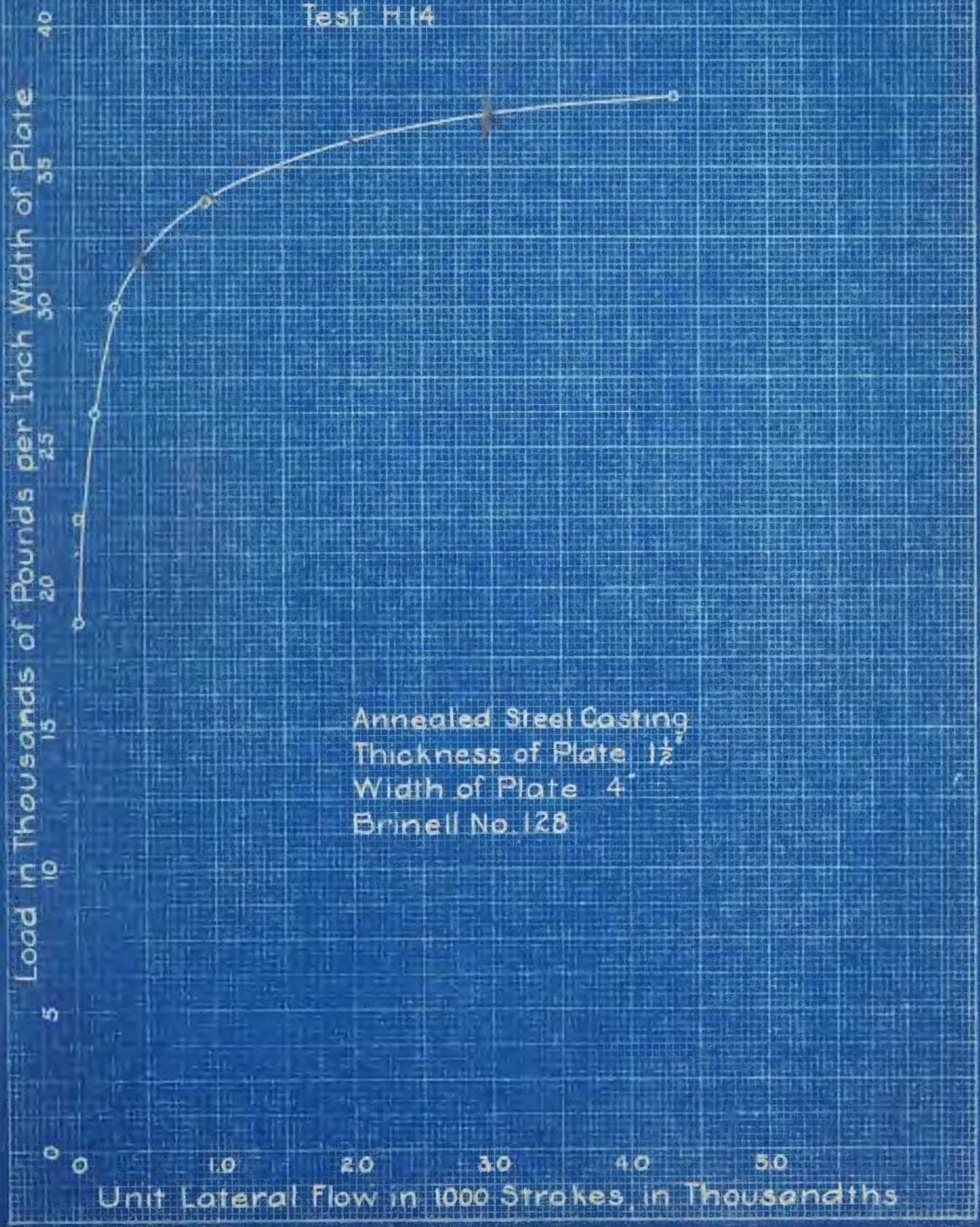
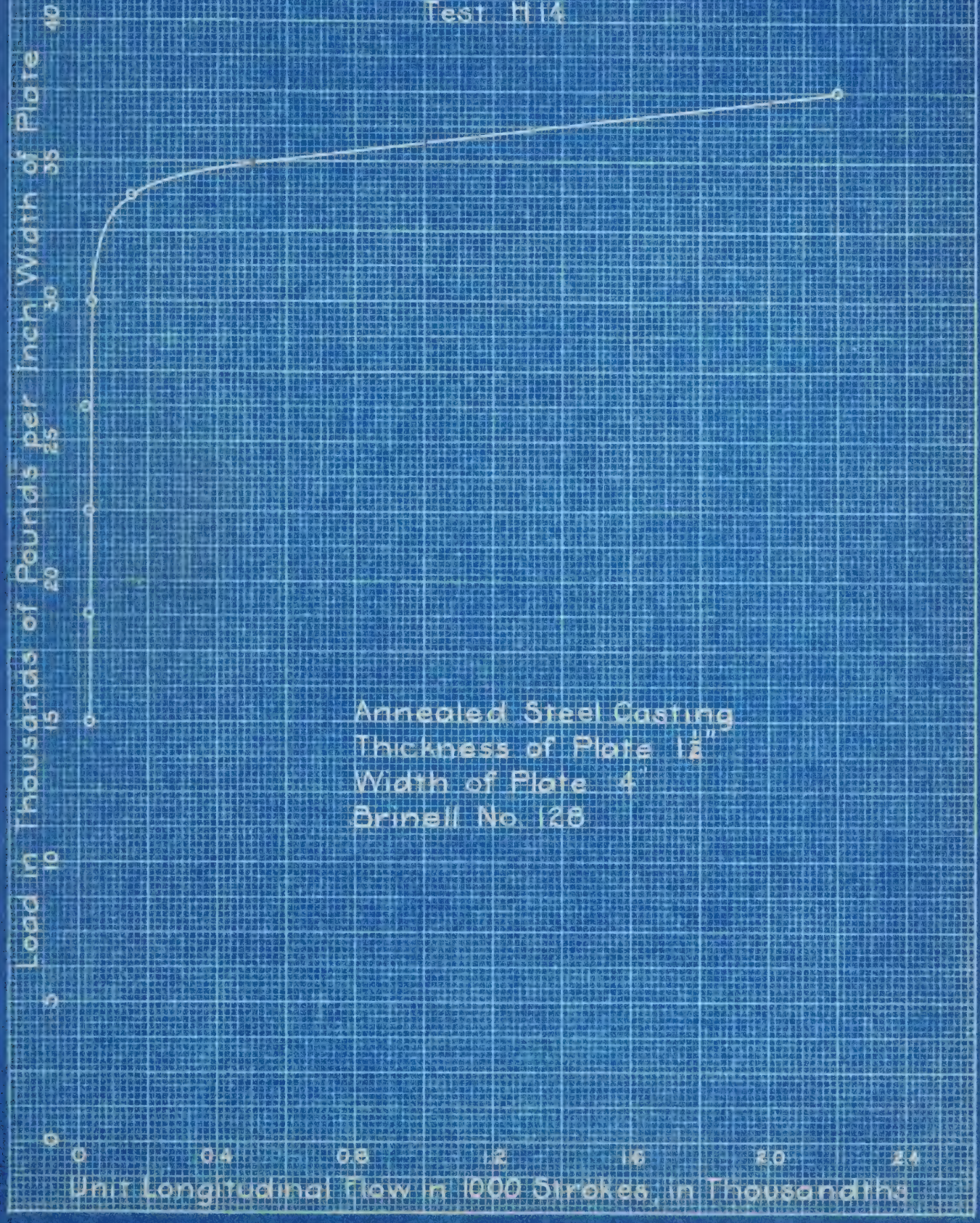


Fig 15 b
Longitudinal Flow of Plate
Due to Rolling
Under Hardened Steel Roller
Diameter of Roller 11⅛"
Test H 14



<u>116 in. Roller on H10.</u> The load-deformation curves for this test are given in Fig. 16. The critical load determined by lateral flow is 34,500 pounds per inch width of plate.

The critical load determined by longitudinal flow is interpreted to be the load at the break in the curve and is 33,300 pounds per inch width of plate.

The curve for spread of roller does not indicate a critical load.

The greater hardness of the roller has no effect on the bearing value of the plate, as shown by the results of this test compared with the results of the test on H14.

Fig 16a
Lateral Flow of Plate
Due to Rolling
Diameter of Roller 116"
Test H10

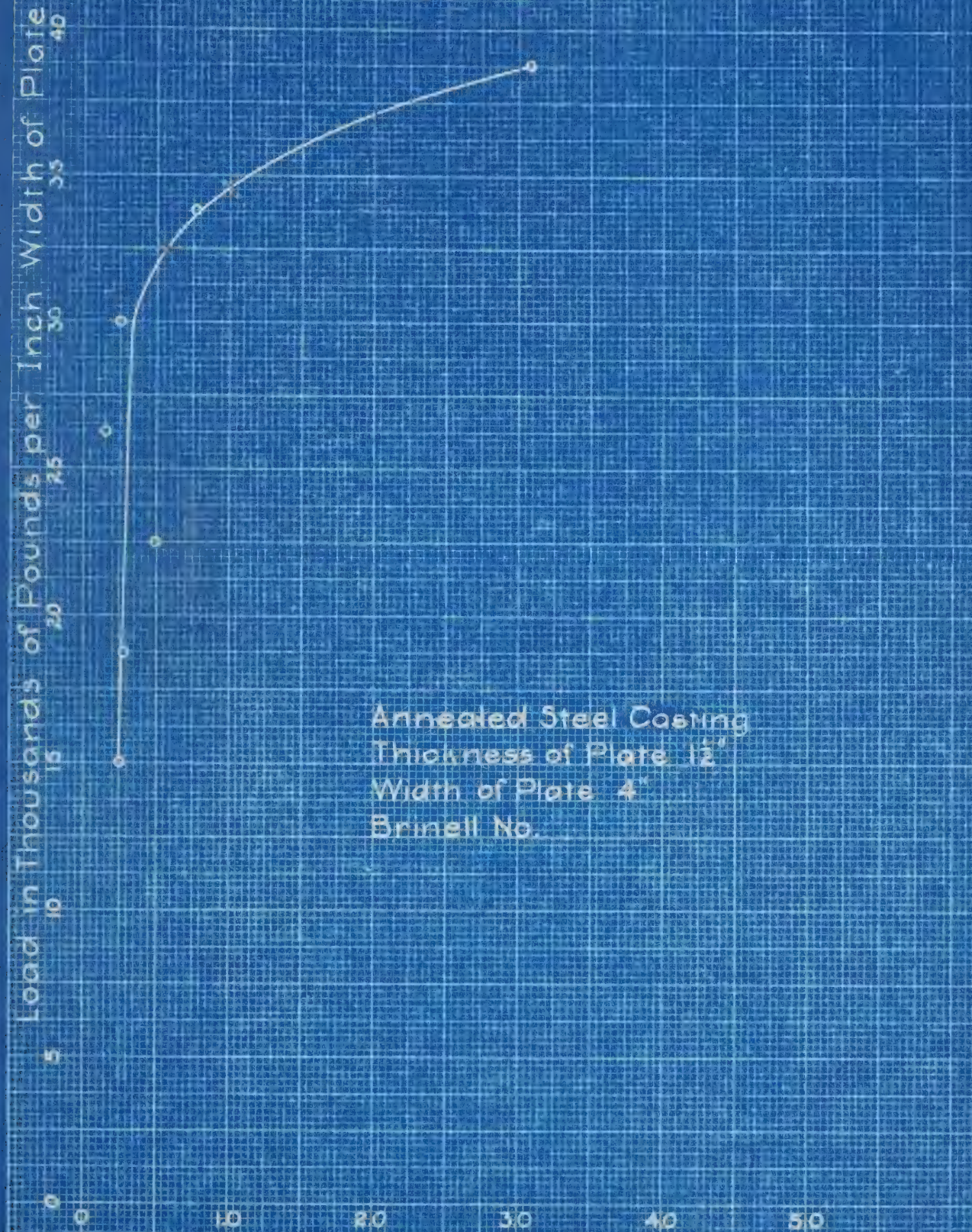
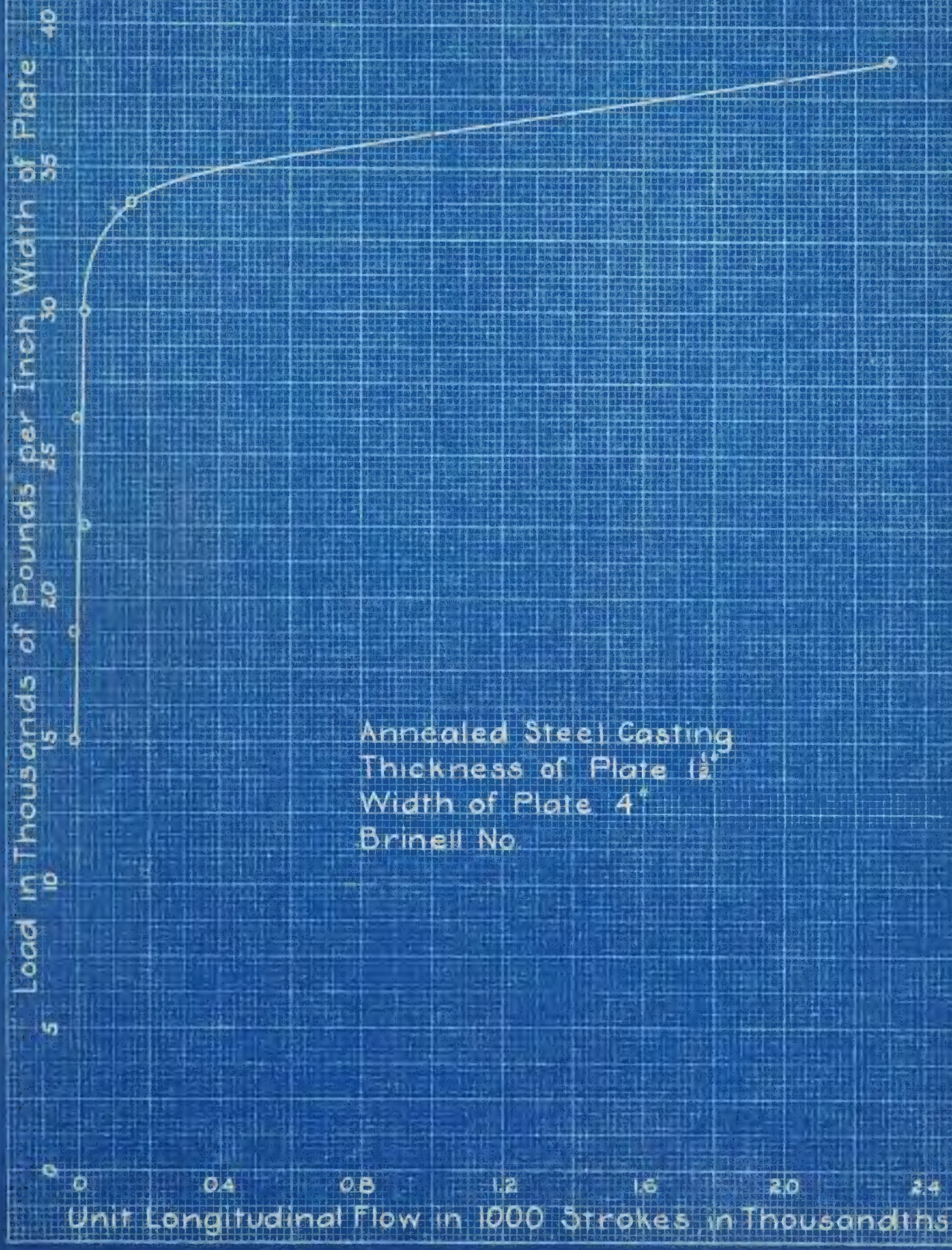


Fig. 16 b
Longitudinal Flow of Plate
Due to Rolling
Diameter of Roller 16"
Test H10



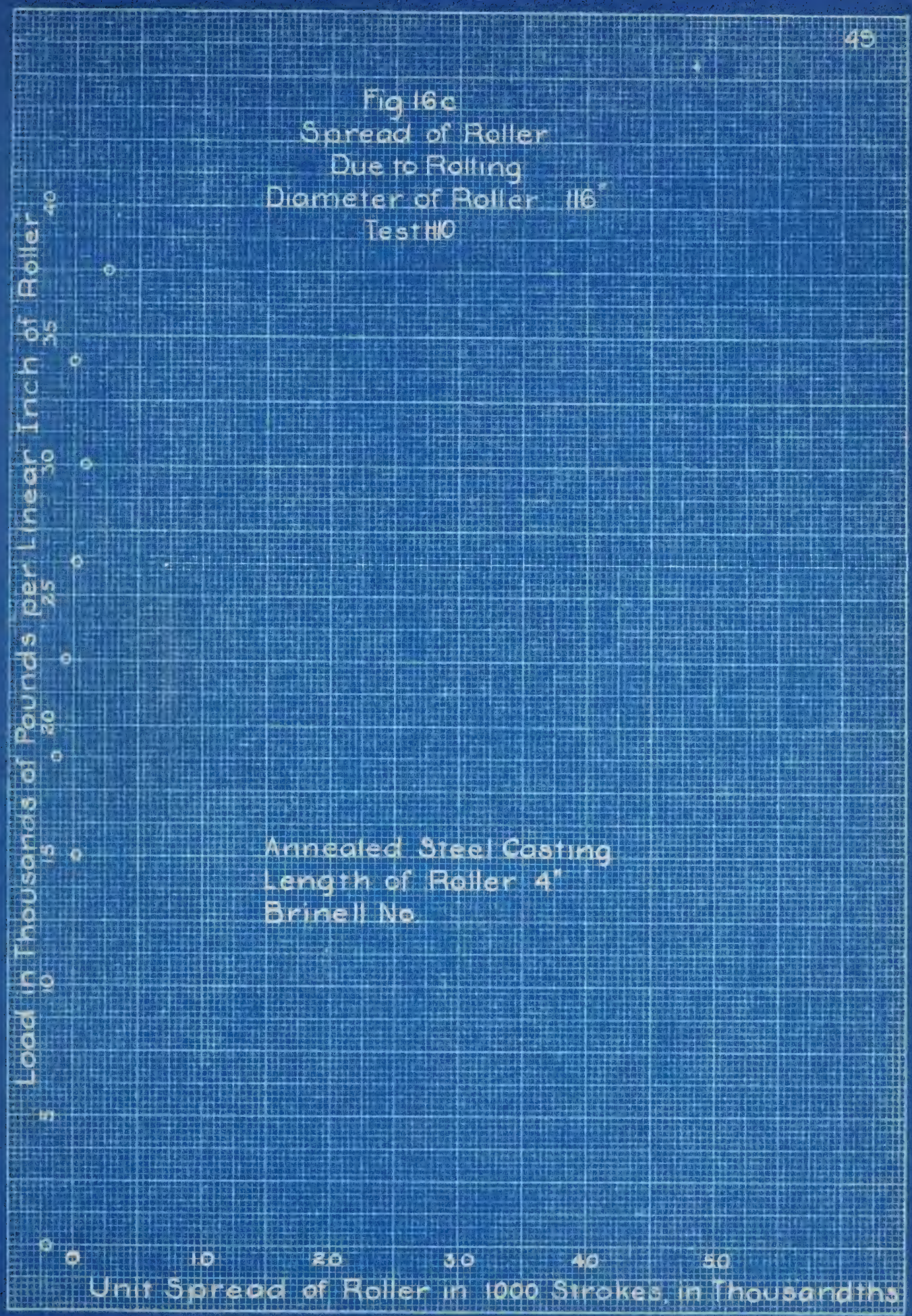


Fig 16c
Spread of Roller
Due to Rolling
Diameter of Roller 116"
Test #10
Load in Thousands of Pounds per Linear Inch of Roller
0
5
10
15
20
25
30
35
40
Annealed Steel Casting
Length of Roller 4"
Brinell No
0
10
20
30
40
50
Unit Spread of Roller in 1000 Strokes in Thousandths

<u>92 inch Roller on Hill.</u> The load-deformation curves for this test are given in Fig. 17.

The critical load determined by lateral flow of plate is 29,300 pounds per inch width of plate.

The critical load determined by longitudinal flow of plate is 30,000 pounds per inch width of plate.

The spread of roller indicates no critical load.

Fig 17a
Lateral Flow of Plate
Due to Rolling
Diameter of Roller 92"
Test #11

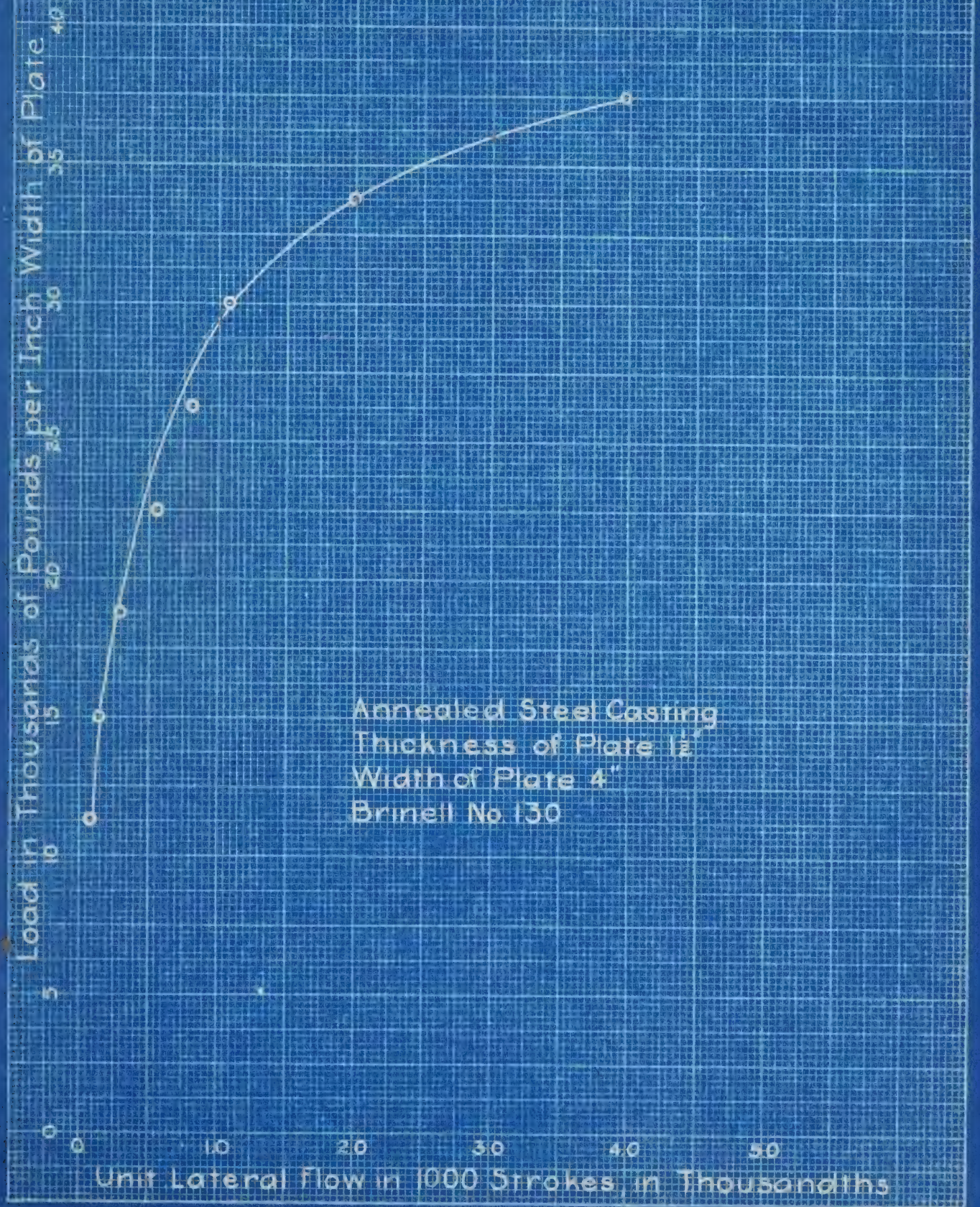


Fig 17 b
Longitudinal Flow of Plate
Due to Rolling
Diameter of Roller 92"
Test H 11

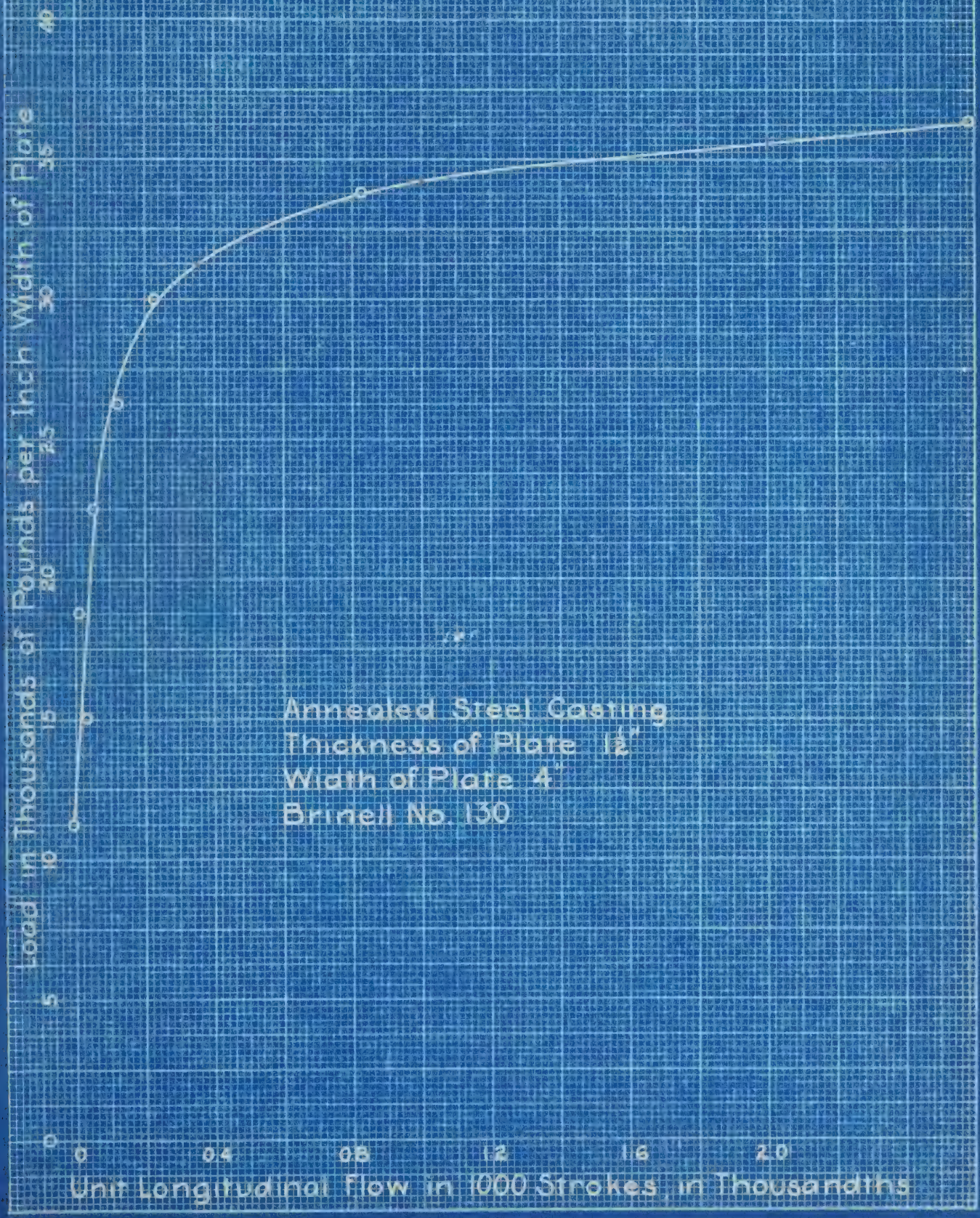


Fig. 17c
Spread of Roller
Due to Rolling
Diameter of Roller 9½"
Test #11
Annealed Steel Casting
Length of Roller 4"
Brinell No. 130
Load in Thousands of Pounds per Linear Inch of Roller
0
5
10
15
20
25
30
35
40
0
1.0
2.0
3.0
4.0
5.0
Unit Spread of Roller in 1000 Strokes, in Thousandths

<u>68 inch Roller on H12.</u> The load deformation curves for this test are given in Fig. 18.

The critical load determined by lateral flow of plate is 22,100 pounds per inch width of plate.

The critical load determined by longitudinal flow of plate is 30,000 pounds per inch width of plate.

The spread of roller indicates no critical load.

Fig 18a
Lateral flow of Plate
Due to Rolling
Diameter of Roller 68"
Test H12

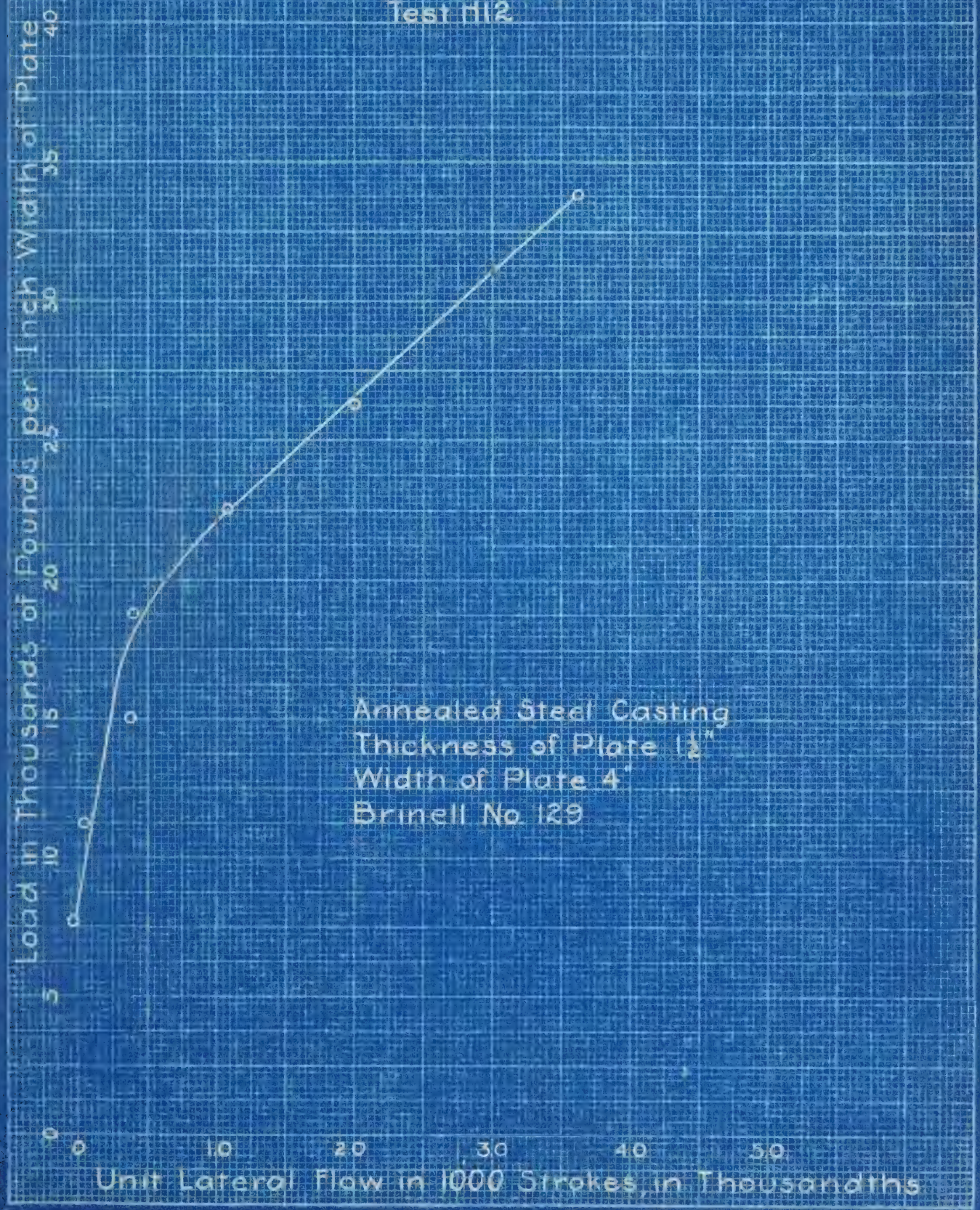


Fig 18b
Longitudinal Flow of Plate
Due to Rolling
Diameter of Roller 68"
Test H12

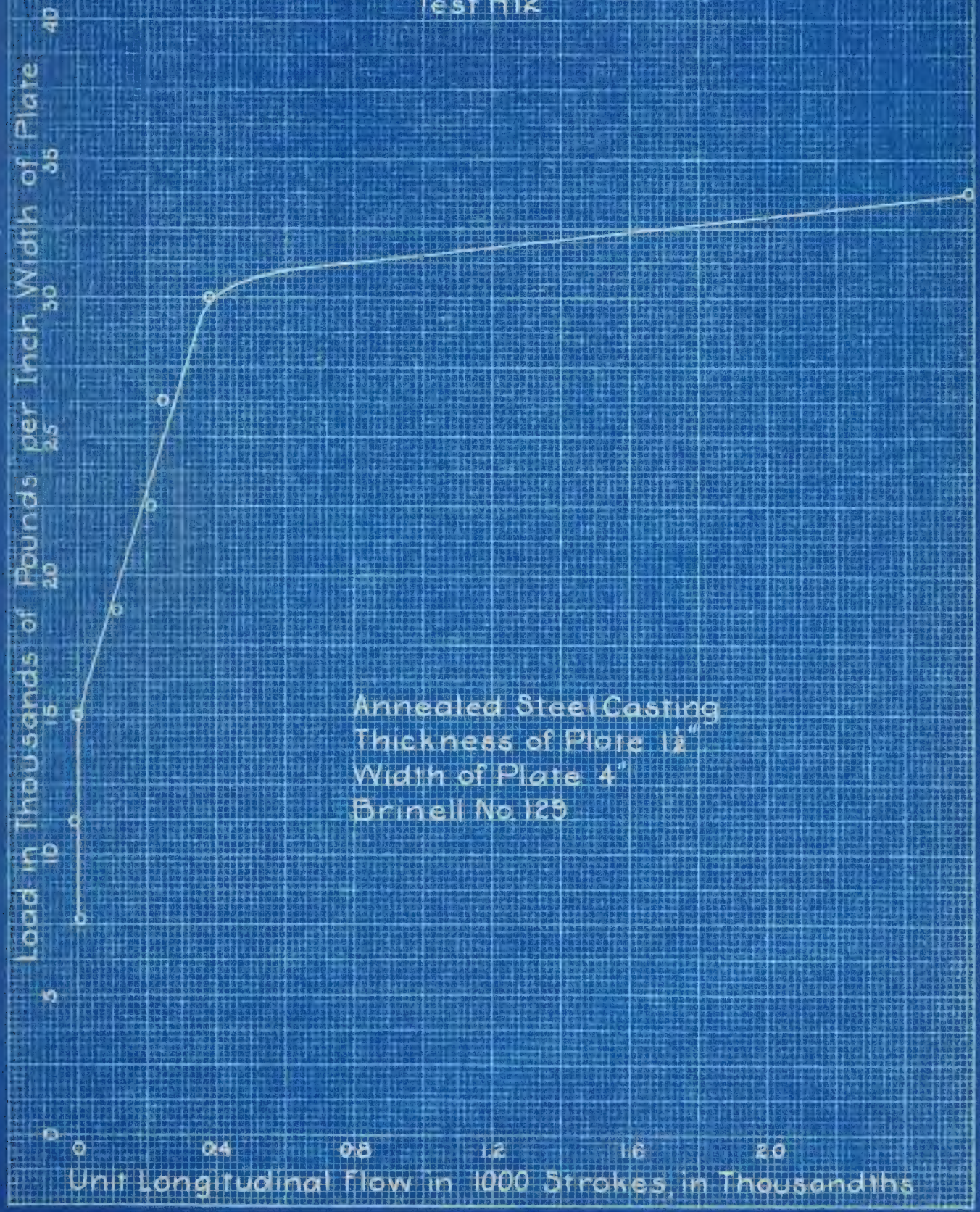
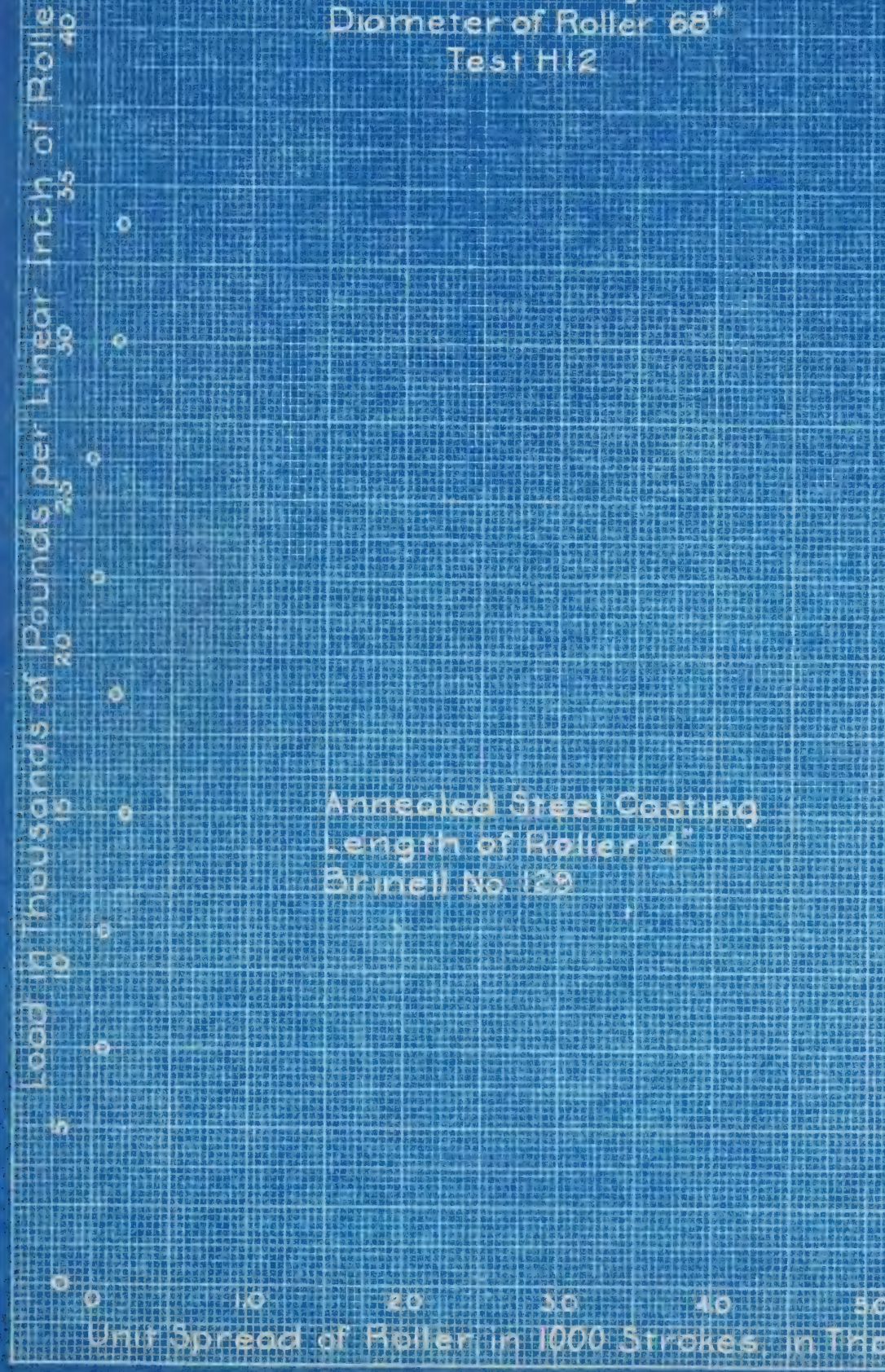


Fig 18c
Spread of Roller
Due to Rolling
Diameter of Roller 68"
Test H12



<u>36 inch Roller on H13.</u> The load-deformation curves of this test are given in Fig. 19

The critical load determined by lateral flow of plate is 21,700 pounds per inch width of plate.

The critical load determined by longitudinal flow of plate is 19,800 pounds per inch width of plate.

The spread of roller indicates no critical load.

Fig 19a
Lateral Flow of Plate
Due to Rolling
Diameter of Roller 36"
Test H13

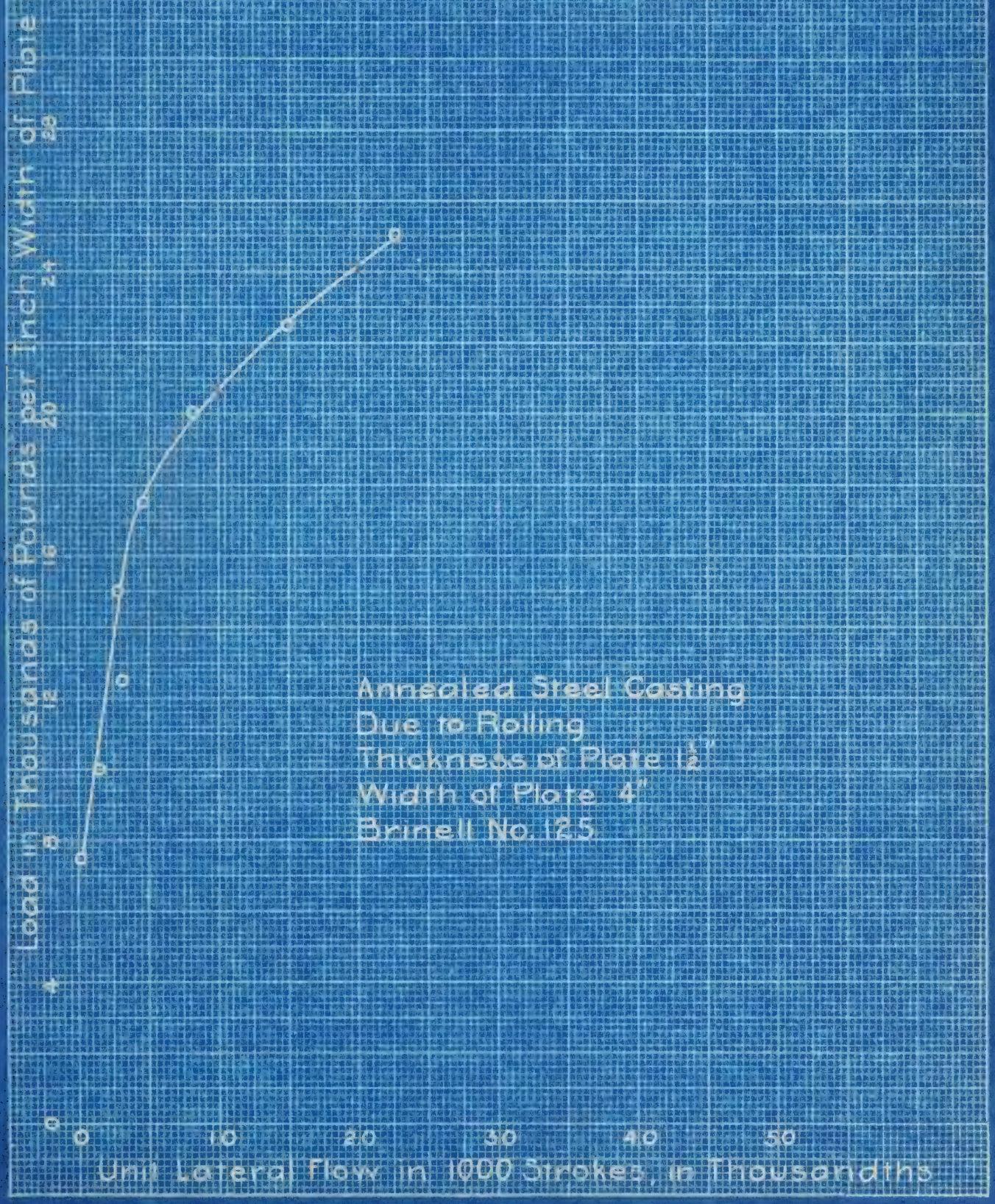


Fig. 19b
Longitudinal Flow of Plate
Due to Rolling
Diameter of Roller 36"
Test H13

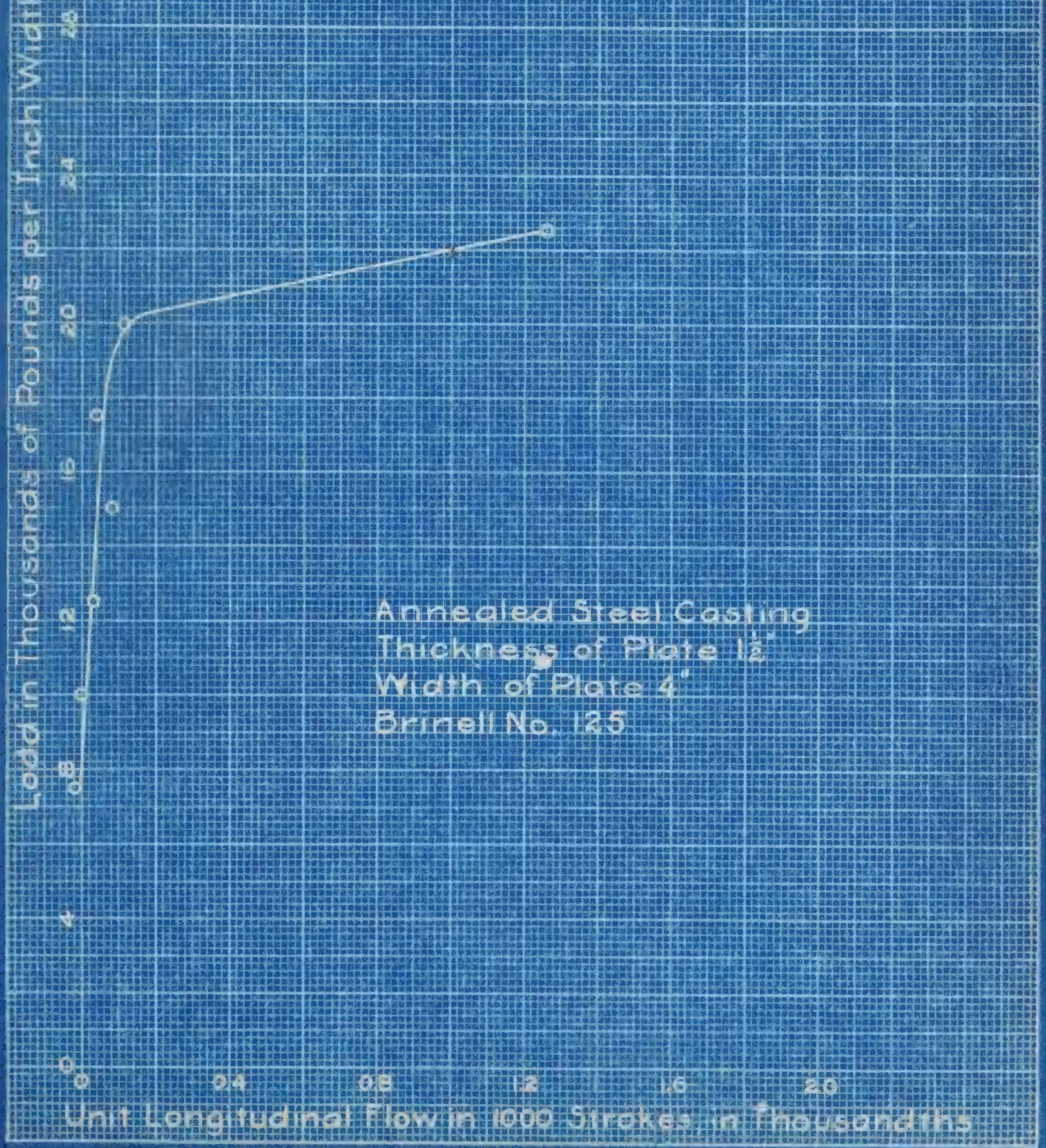
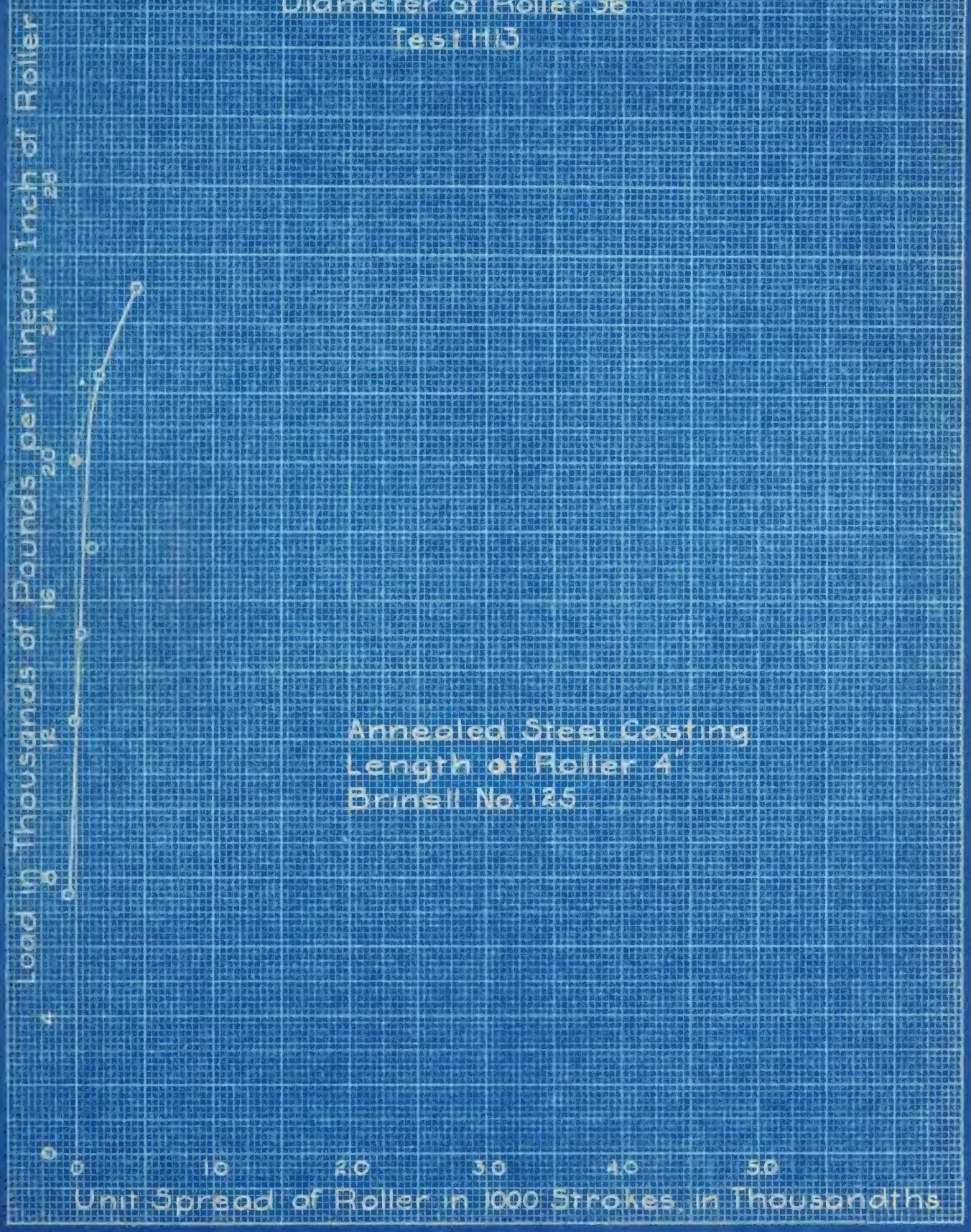


Fig 19c
Spread of Roller
Due to Rolling
Diameter of Roller 36"
Test H13



Annealed Steel Casting
Length of Roller 4"
Brinell No. 125

23½ inch Roller on H1 and H2. This was the first test on small rollers. It appeared that two blocks could be rolled at the same time without much additional time or effort, one above and one below tthe roller. The idea was tried and great difficulty was encountered in maintaining even distribution of load on both blocks; so the method was abandoned. The top of the block is defined as the rolled surface although in H1 it was the lower face.

The load-deformation curves for this test are given in Fig. 20.

The critical load determined by lateral flow from the test on H1 is 21,800 pounds per inch width of plate and from the test on H2 is 21,800 pounds per inch width of plate.

The critical load determined by longitudinal flow is interpreted to be at the break in the curve. From the test on H1 it is 21,100 pounds per inch width of plate and from the test on H2 it is 22,000 pounds per inch width of plate.

The critical load determined by the spread of roller from the test on H1 is 23,500 pounds per linear inch of roller and from the test on H2 is 21,800 pounds per linear inch of roller.

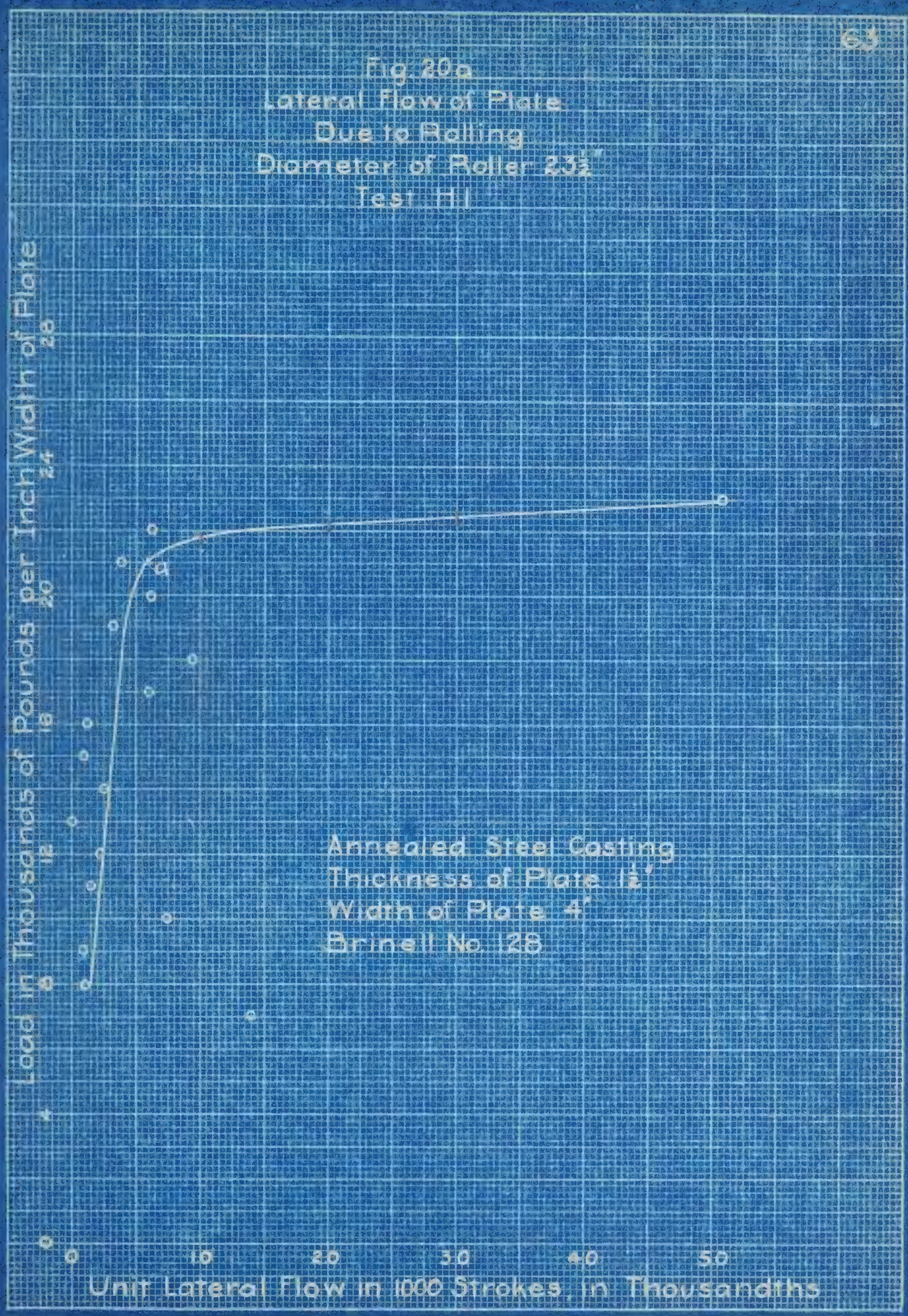
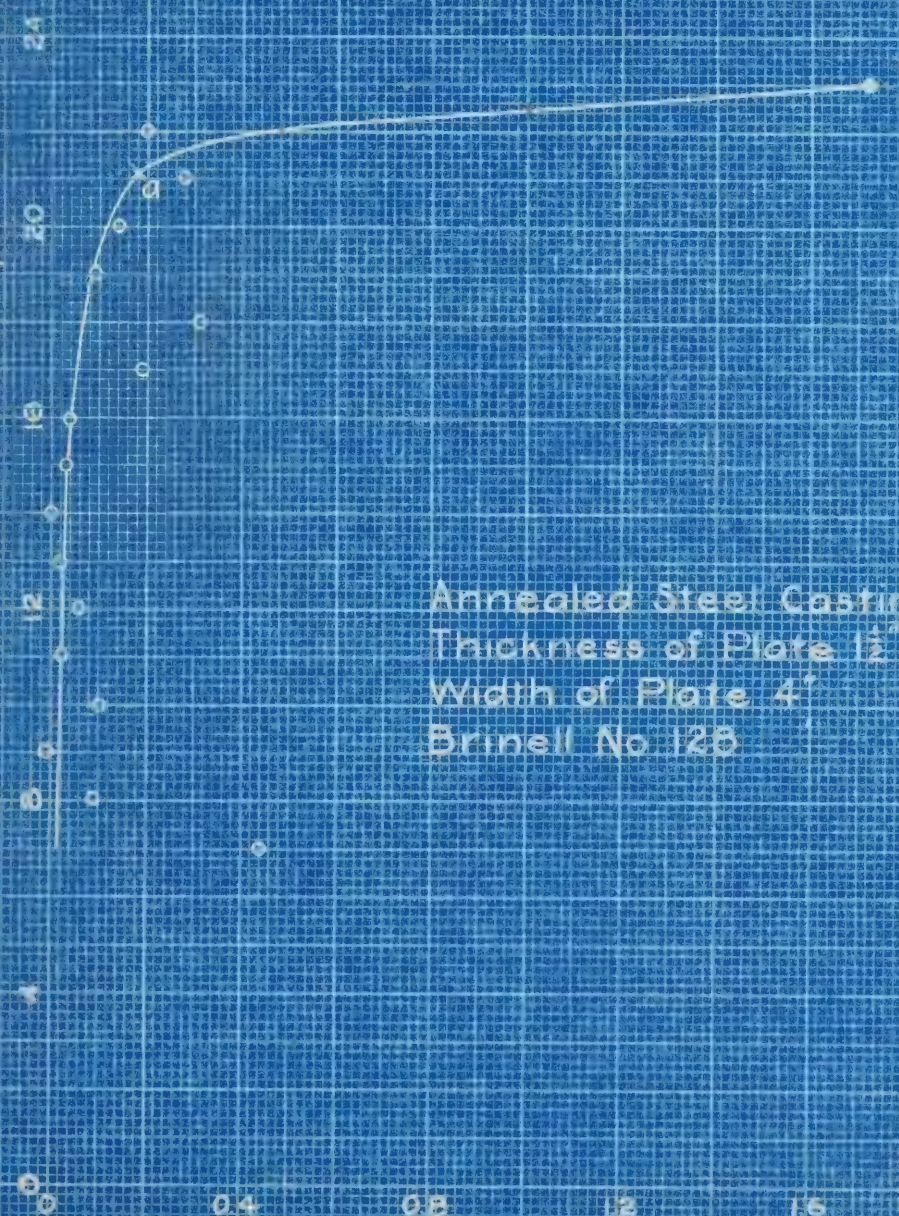


Fig. 20a
Lateral Flow of Plate
Due to Rolling
Diameter of Roller 23½"
Test #11
Load in Thousands of Pounds per Inch Width of Plate
0
4
8
12
16
20
24
28
Annealed Steel Casting
Thickness of Plate 1½"
Width of Plate 4"
Brinell No. 128
0
10
20
30
40
50
Unit Lateral Flow in 1000 Strokes in Thousandths

Fig 20b
Longitudinal Flow of Plate
Due to Rolling
Diameter of Roller 23½"
Test H1



Annealed Steel Casting
Thickness of Plate ½"
Width of Plate 4"
Brinell No. 126

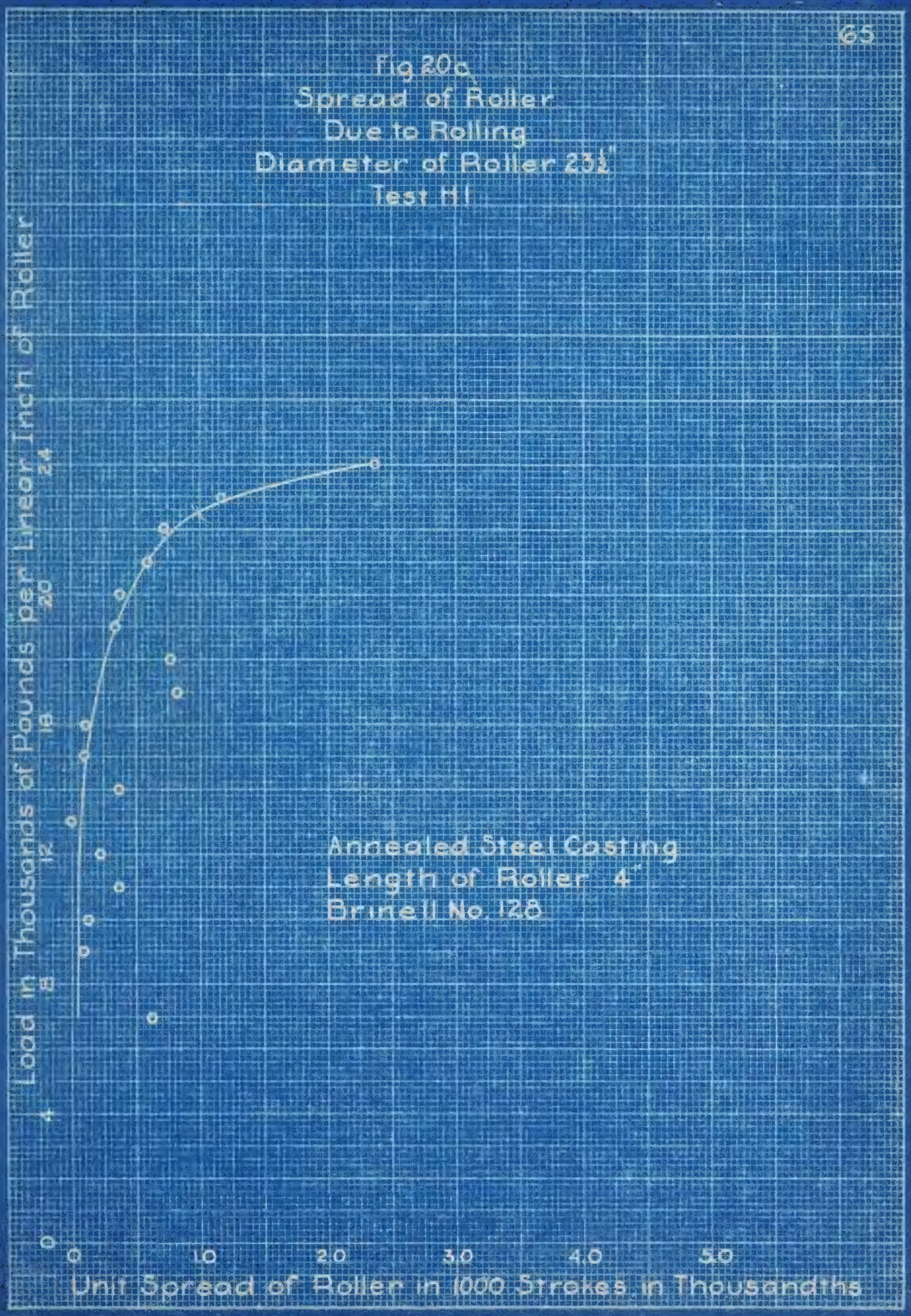


Fig 20a
Spread of Roller
Due to Rolling
Diameter of Roller 25½"
Test H1
Load in Thousands of Pounds per Linear Inch of Roller
0
4
8
12
16
20
24
Annealed Steel Casting
Length of Roller 4"
Brinell No. 120
0
1.0
2.0
3.0
4.0
5.0
Unit Spread of Roller in 1000 Strokes in Thousandths

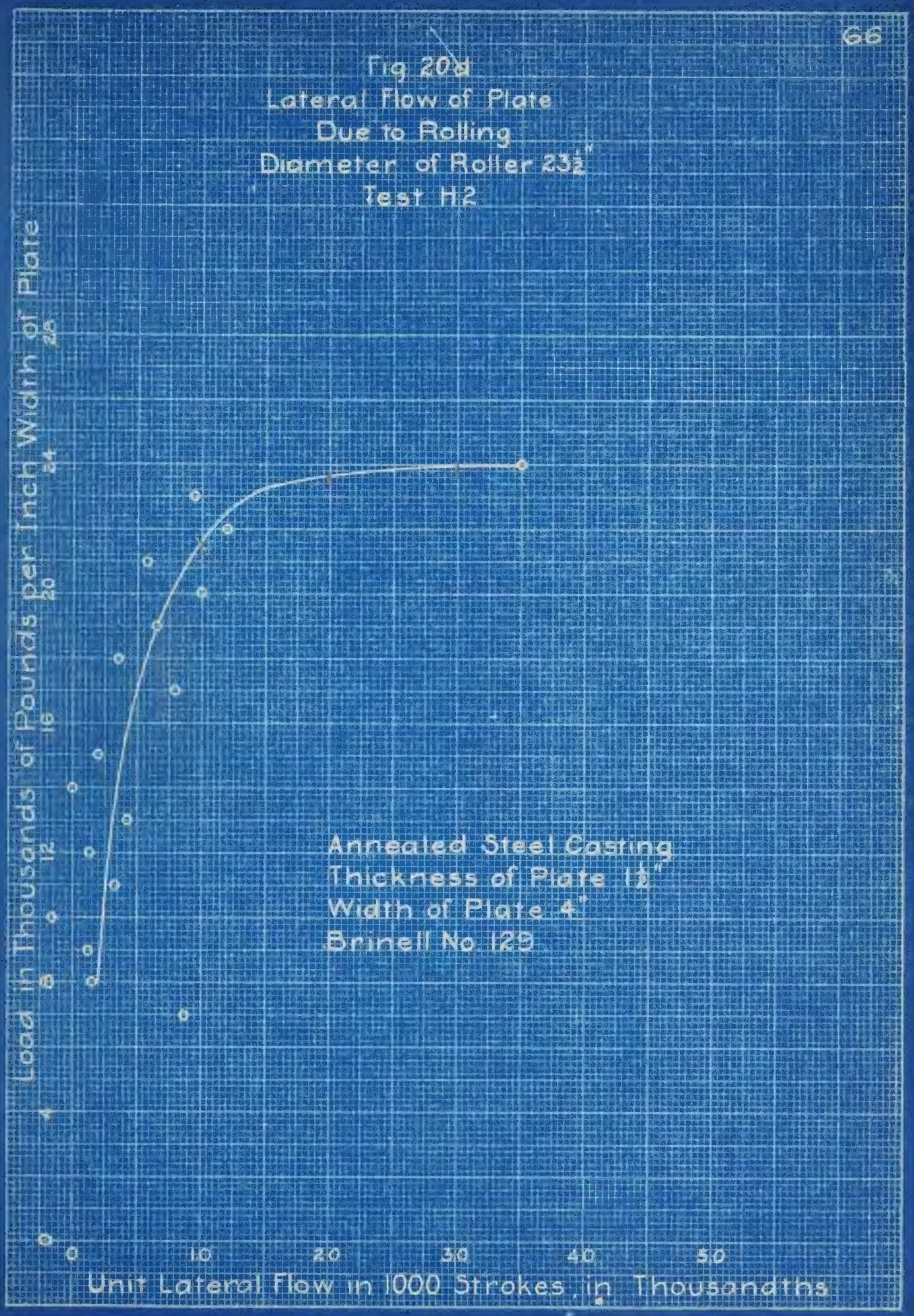


Fig 20a
Lateral Flow of Plate
Due to Rolling
Diameter of Roller 23½"
Test H2
Load in Thousands of Pounds per Inch Width of Plate
0
4
8
12
16
20
24
28
Annealed Steel Casting
Thickness of Plate 1½"
Width of Plate 4"
Brinell No. 129
0
10
20
30
40
50
Unit Lateral Flow in 1000 Strokes in Thousandths

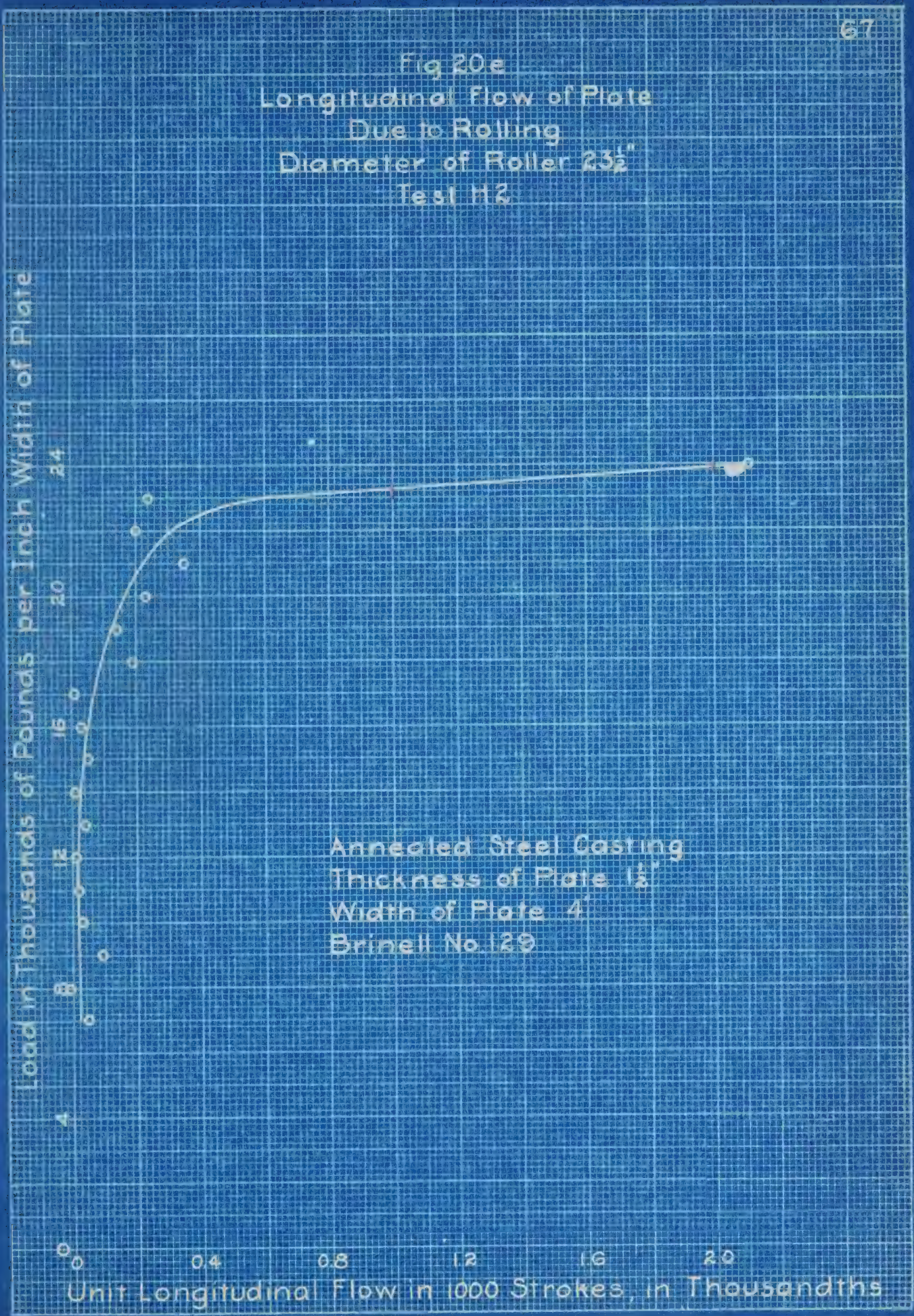
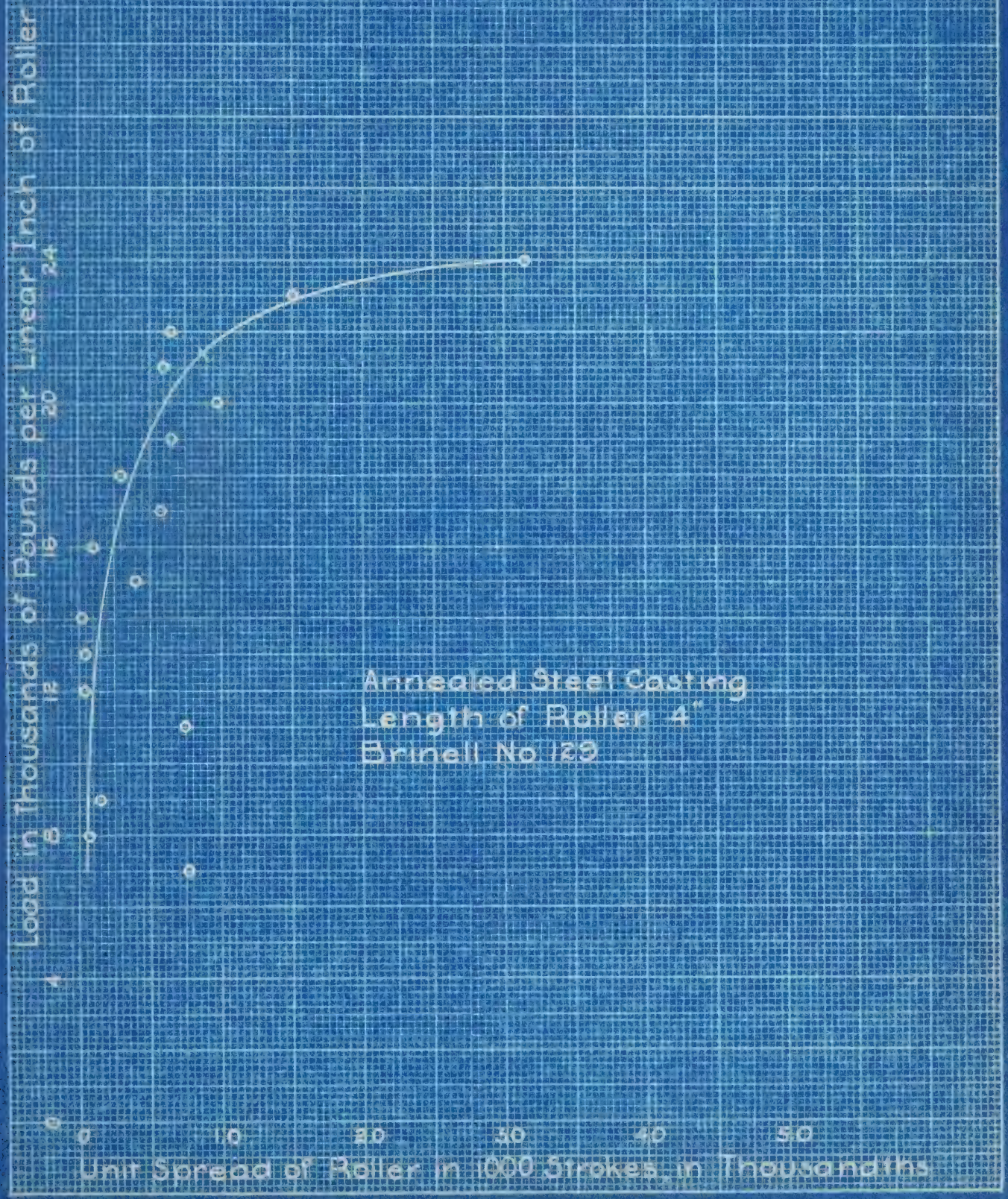


Fig 20e
Longitudinal Flow of Plate
Due to Rolling
Diameter of Roller 23½"
Test H2
Annealed Steel Casting
Thickness of Plate 1½"
Width of Plate 4"
Brinell No. 129
Load in Thousands of Pounds per Inch Width of Plate
0
4
8
12
16
20
24
0
0.4
0.8
1.2
1.6
2.0
Unit Longitudinal Flow in 1000 Strokes, in Thousandths

Fig 20T
Spread of Roller
Due to Rolling
Diameter of Roller 2 3/32"
Test H2



<u>16" Roller on H5.</u> The excessive deformation in the roller at the first loads may have been due to loose micrometer points. They were hammered into the roller after the second increment.

The load-deformation curves of this test are given in Fig. 21.

The critical load determined from the lateral flow is 15,200 pounds per inch width of plate and from the spread of roller it is 14,800 pounds per linear inch of roller.

The critical load determined from the longitudinal flow is interpreted to be that load at the reversal of curvature and is 13,300 pounds per inch width of plate.

Fig 21a
Lateral Flow of Plate
Due to Rolling
Diameter of Roller 16"
Test H5

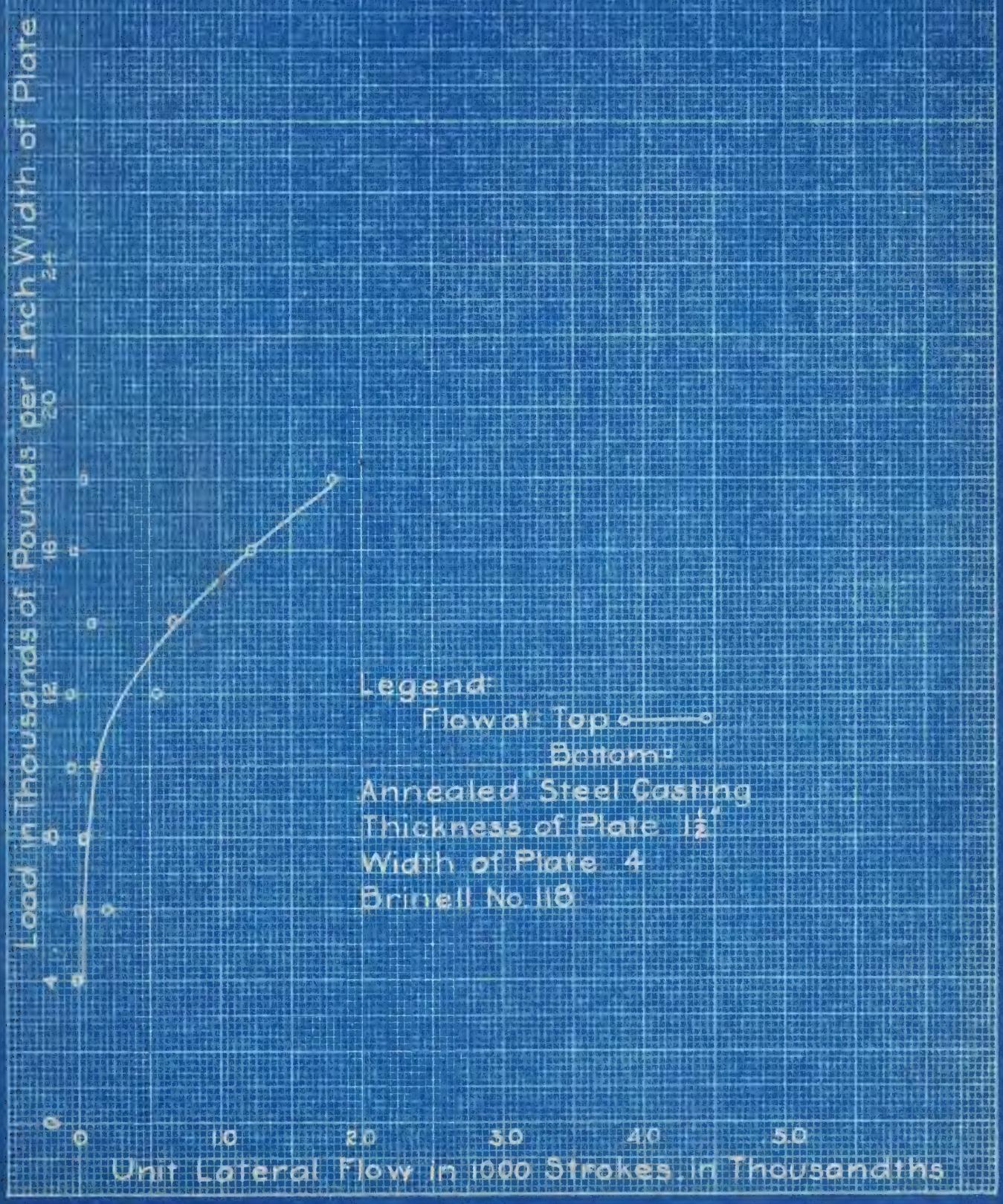


Fig 21b
Longitudinal Flow of Plate
Due to Rolling
Diameter of Roller 16"
Test H5

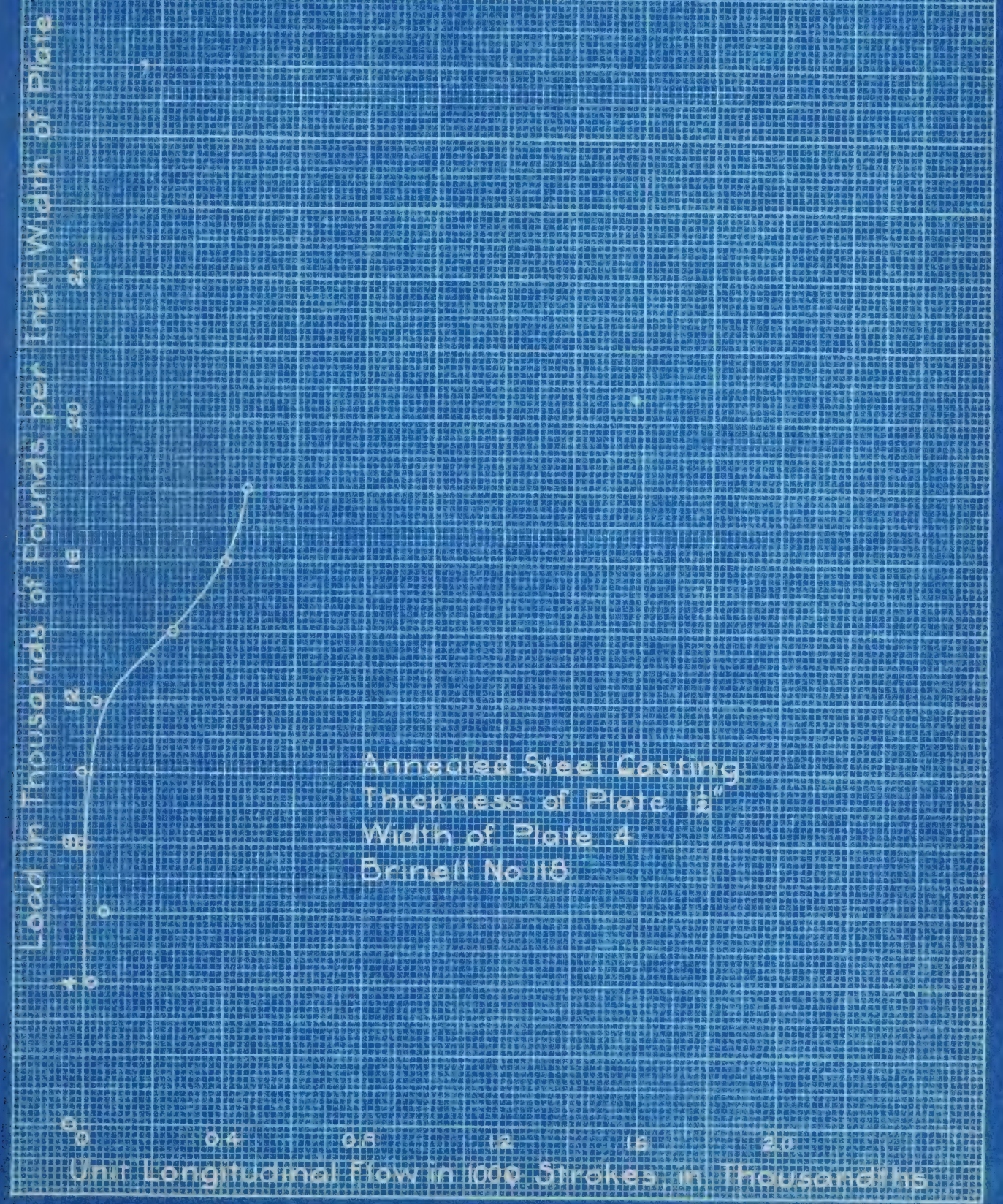
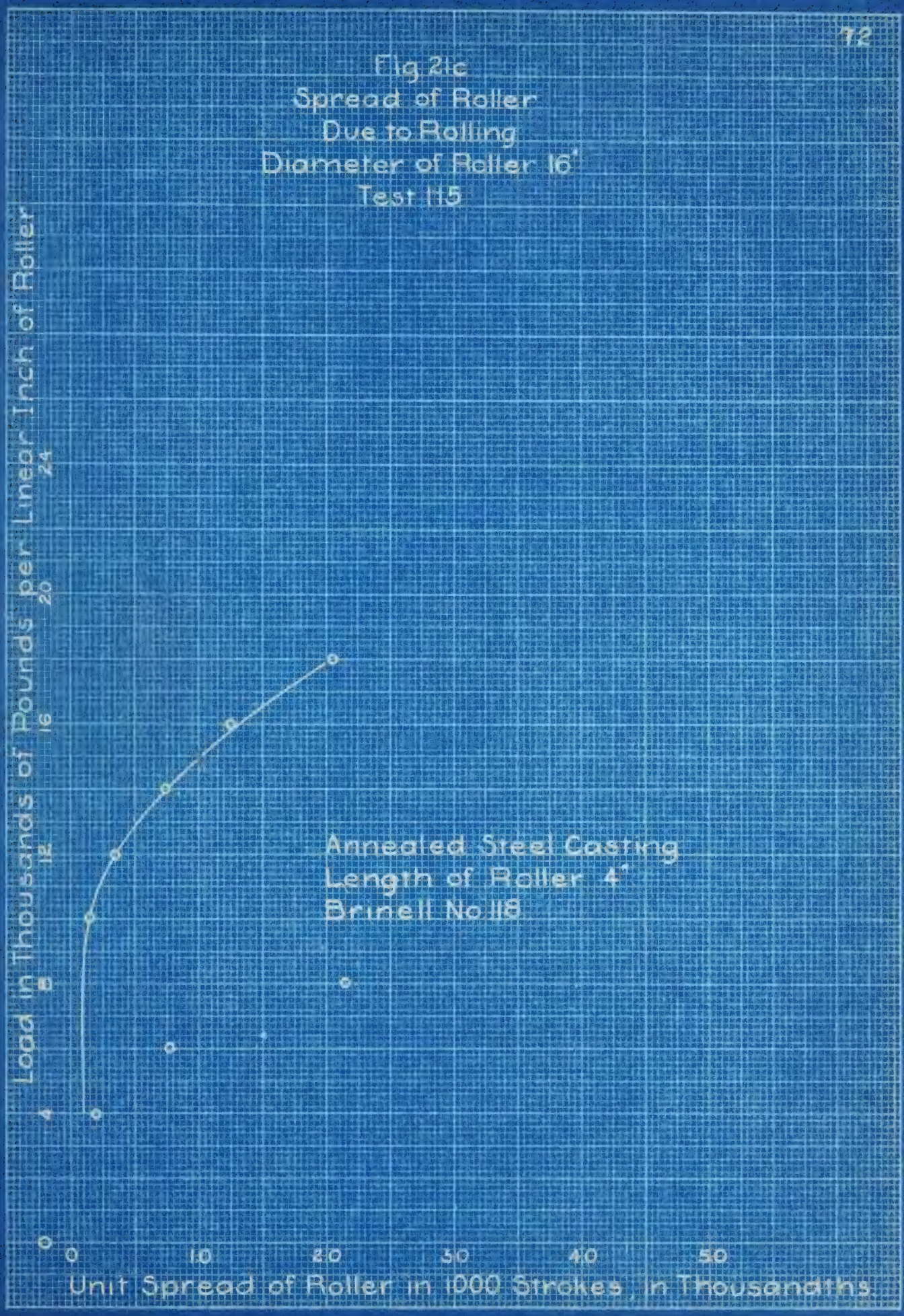


Fig 21c
Spread of Roller
Due to Rolling
Diameter of Roller 16"
Test 115



<u>15 Inch Roller on H3.</u> The load-deformation curves of this test are given in Figure 22.

The critical load determined from the lateral flow is 14,500 pounds per inch width of plate and from the spread of roller it is only 8200 pounds per linear inch of roller. The writer has no explanation for the great difference.

The critical load determined by longitudinal flow is interpreted to be at the point of reversal of curvature and is 15,700 pounds per inch width of plate.

The high value of the Brinell number may be due to the fact that the hardness test was not made until the inverted block had been tested under the 10 inch roller.

Fig 22a
Lateral Flow of Plate
Due to Rolling
Diameter of Roller 12"
Test H3

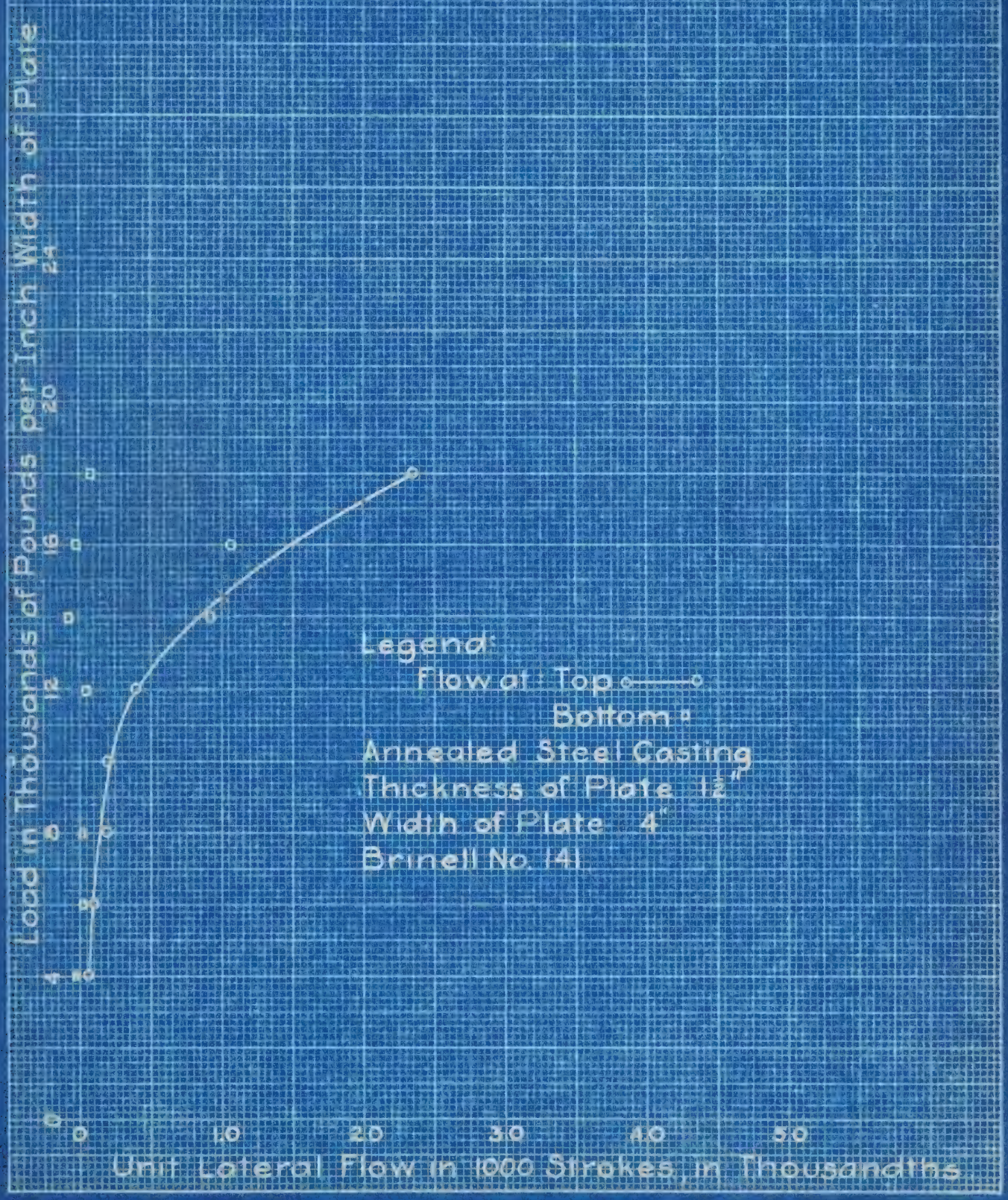


Fig 22b
Longitudinal Flow of Plate
Due to Rolling
Diameter of Roller 12"
Test H3

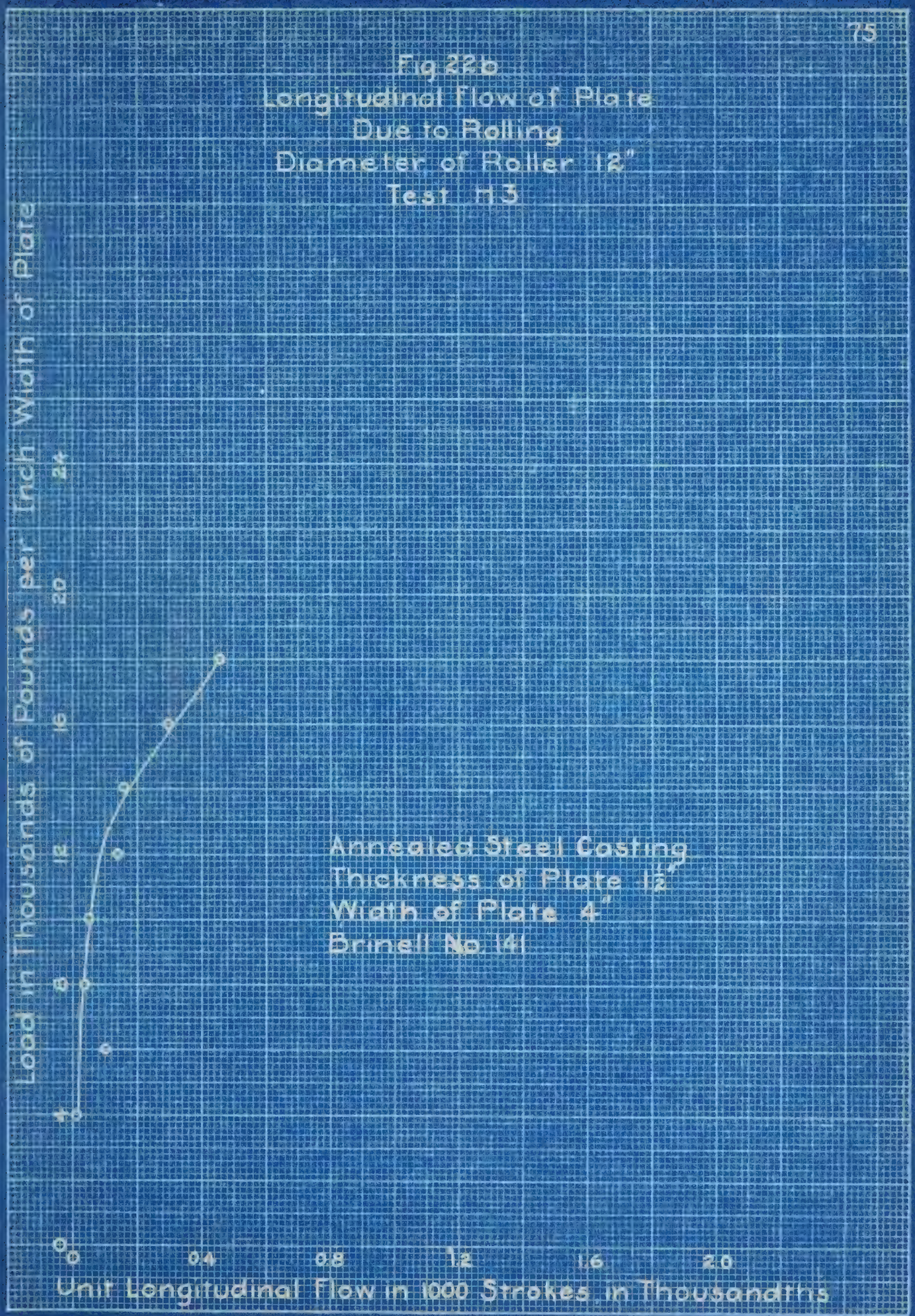
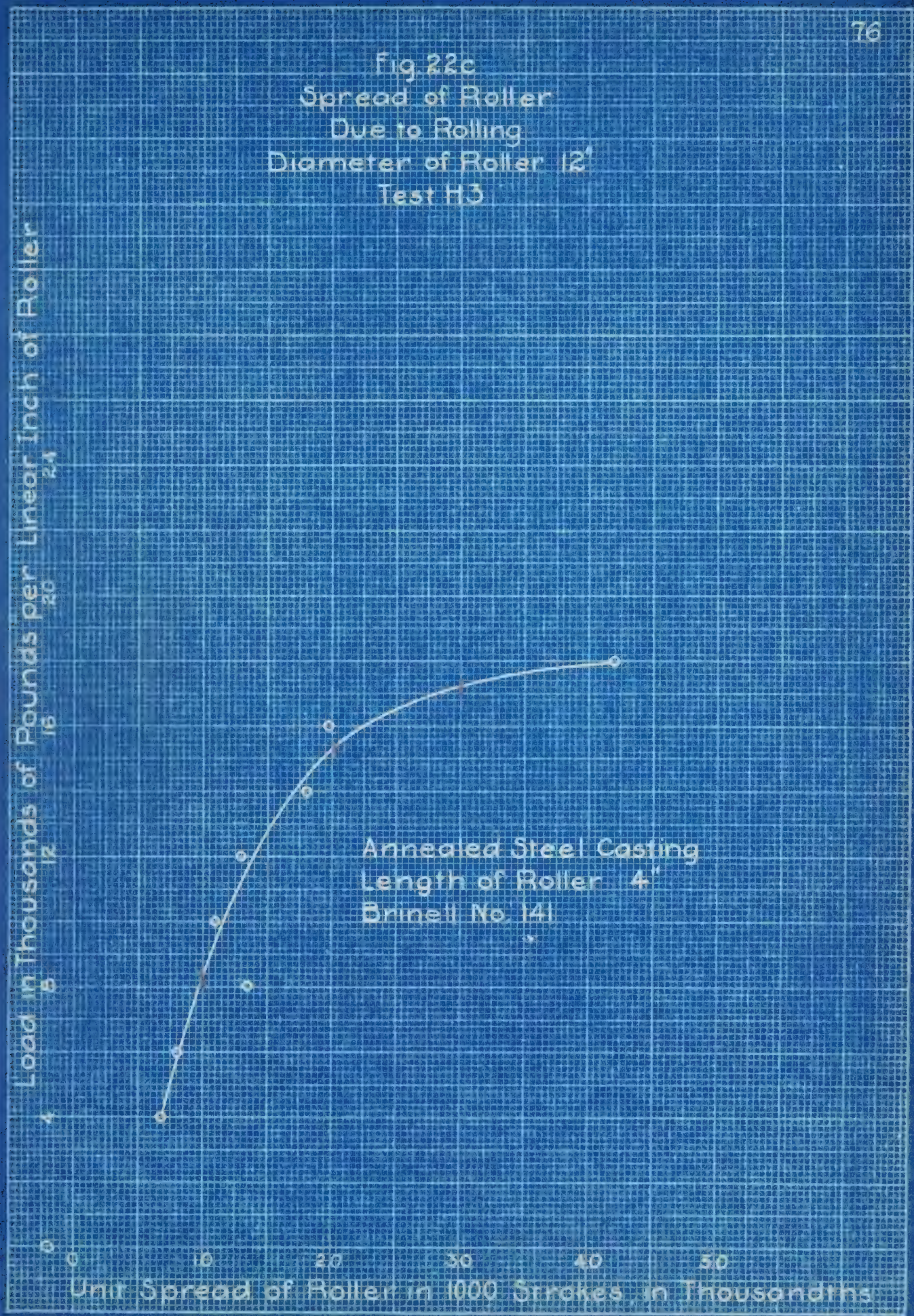


Fig 22c
Spread of Roller
Due to Rolling
Diameter of Roller 12"
Test H5



<u>10 Inch Roller on H3A.</u> The load-deformation curves of this test are given in Fig. 23.

The critical load determined from the lateral flow is 10,100 pounds per inch width of plate and from the spread of roller it is 11,400 pounds per linear inch of roller.

The critical load determined by longitudinal flow is interpreted to be at the point of reversal of curvature and is 13,000 pounds per inch width of plate.

Fig 23a
Lateral Flow of Plate
Due to Rolling
Diameter of Roller 10"
Test H3A

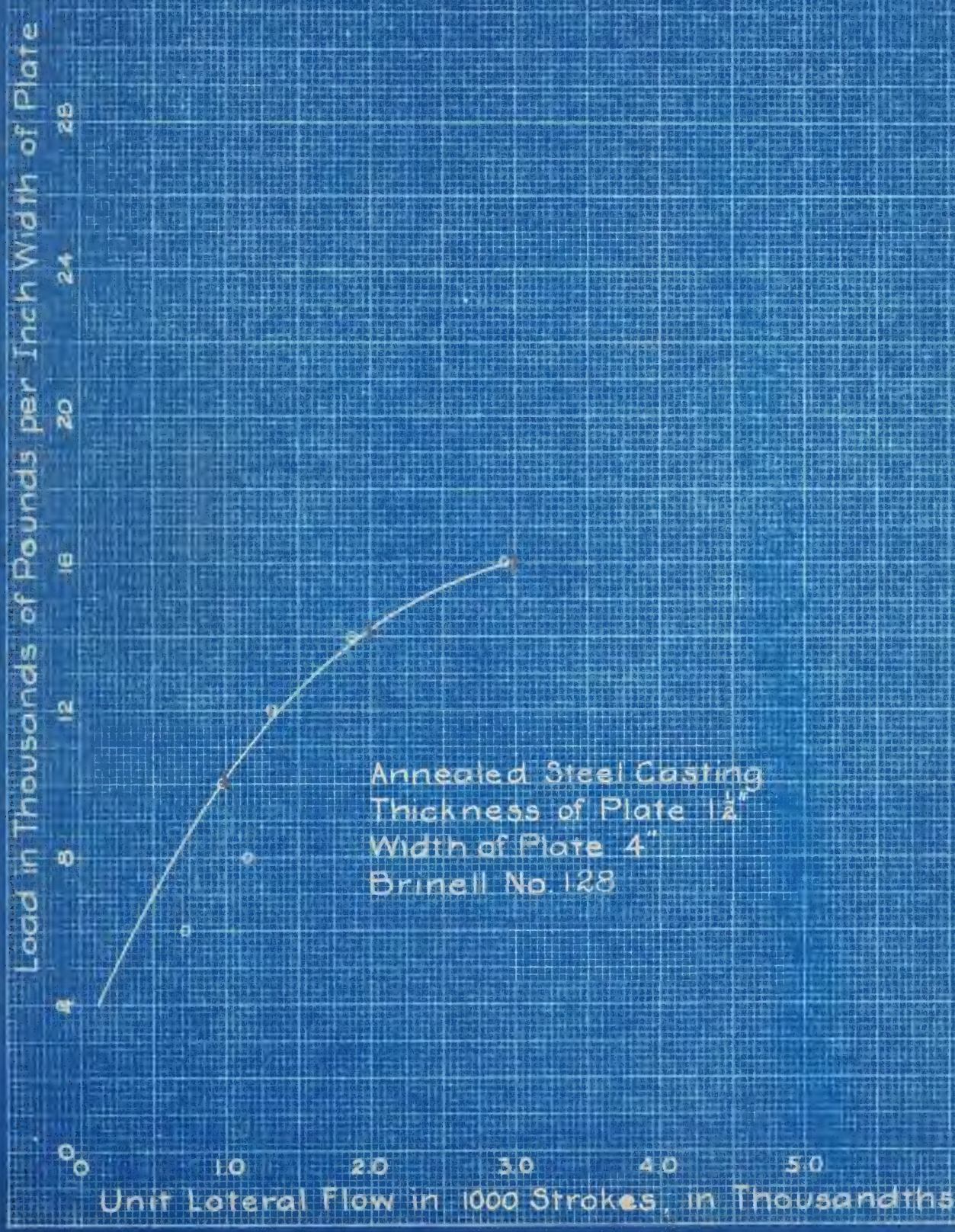


Fig 23b
Longitudinal Flow of Plate
Due to Rolling
Diameter of Roller 10"
Test H3A

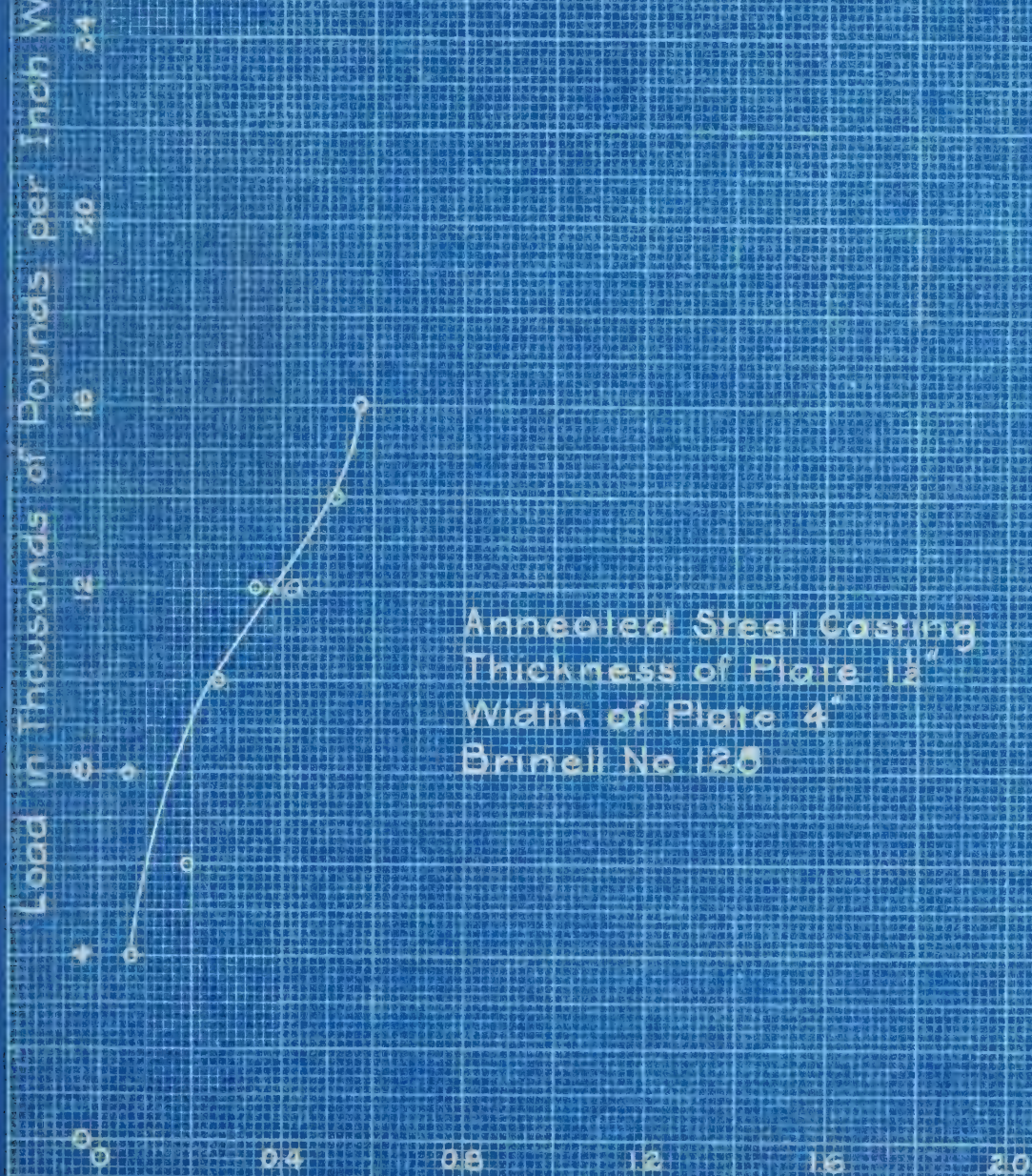
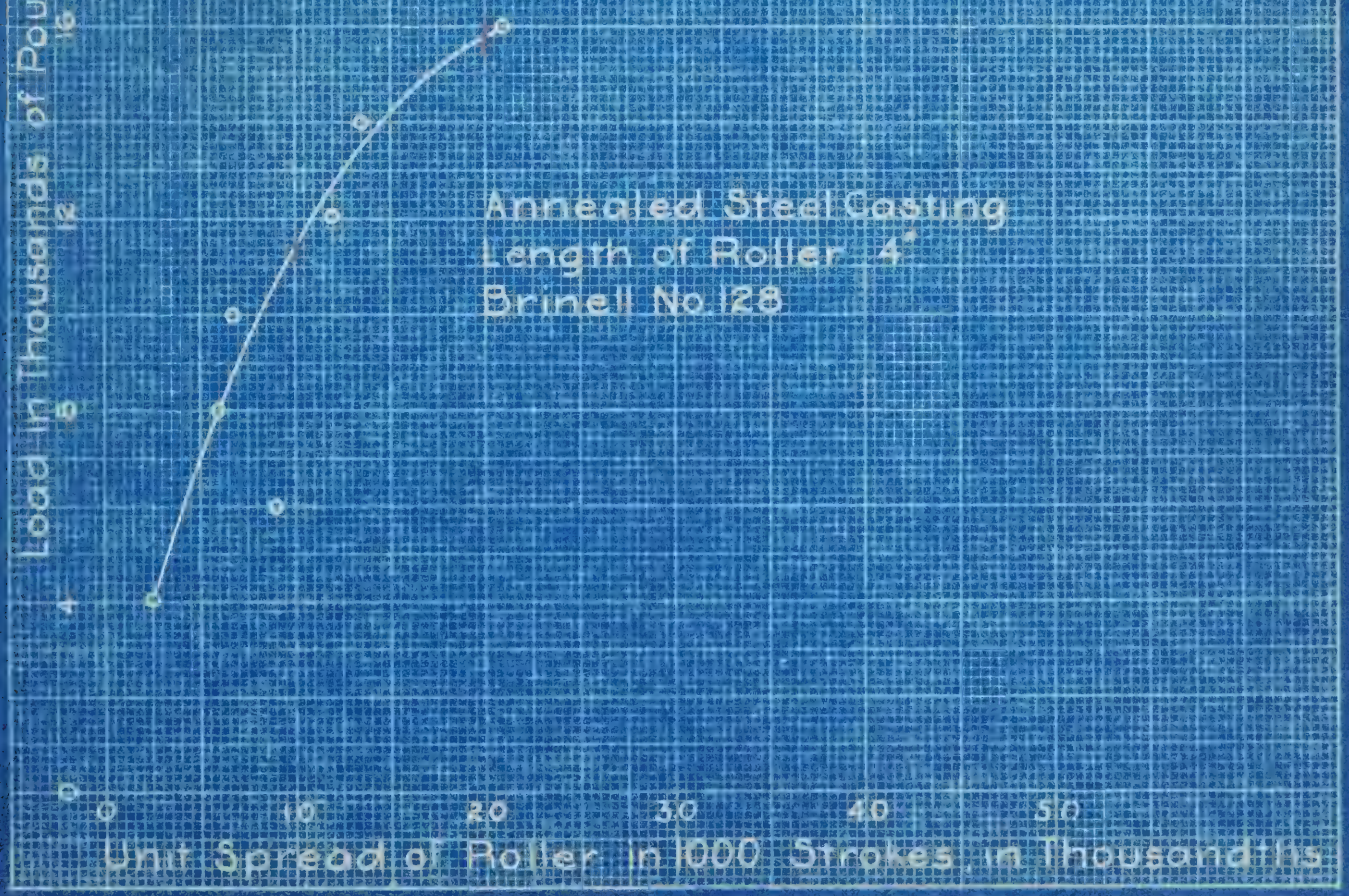


Fig 25a
Spread of Roller
Due to Rolling
Diameter of Roller 10"
Test H 5A



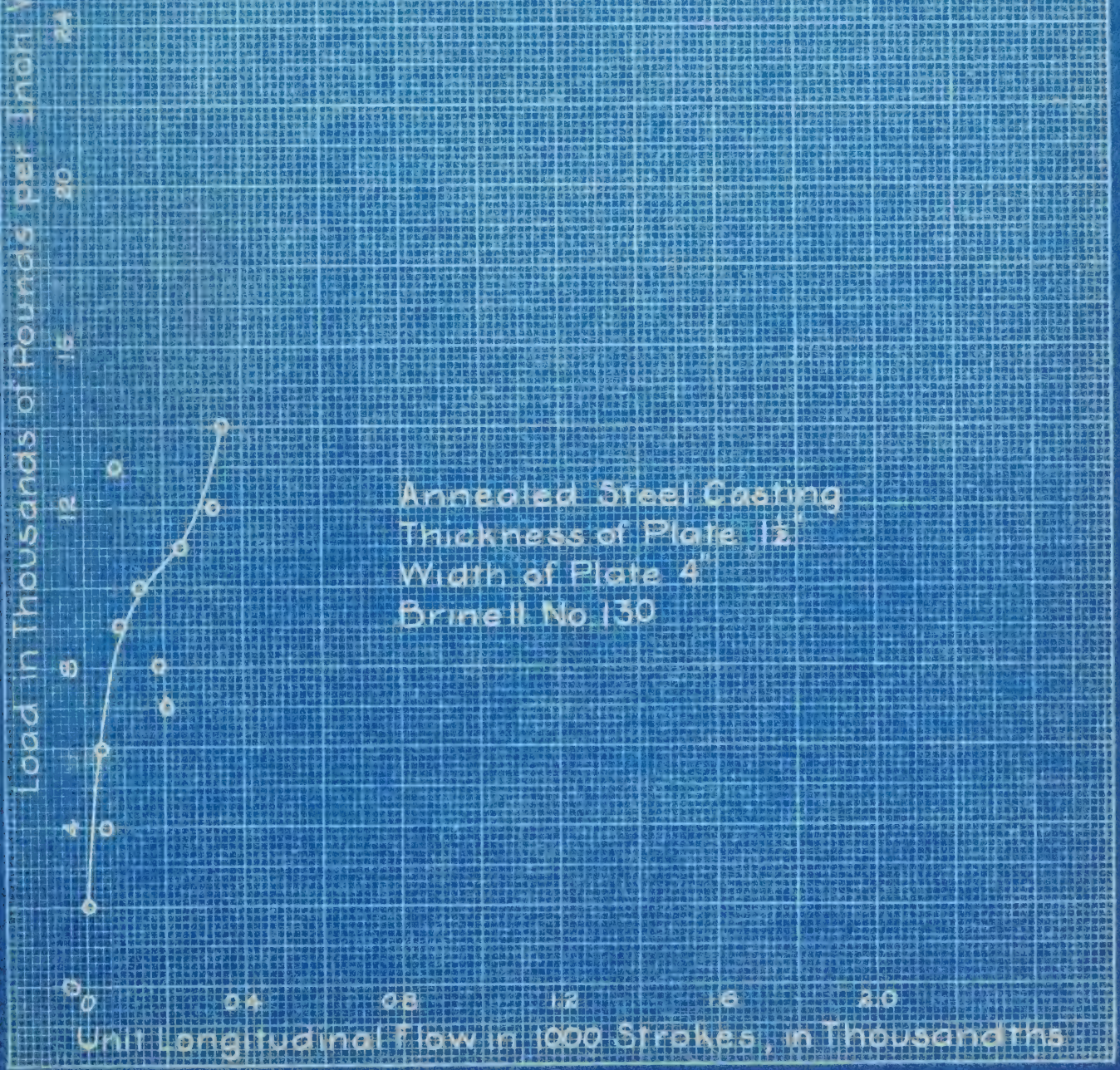
<u>8 Inch Roller on M5.</u> The load deformation curves of this test are given in Fig. 24.

The critical load determined from the lateral flow is 10,800 pounds per inch width of plate and from the spread of roller it is 11,900 pounds per linear inch of roller.

The curve of longituinal flow indicates neither a reversal of curvature nor break.

Fig 24a
Lateral Flow of Plate
Due to Rolling
Diameter of Roller 8"
Test 115A
Load in Thousands of Pounds per Inch Width of Plate
0
2
4
6
8
10
12
14
16
Annealed Steel Casting
Thickness of Plate 1½"
Width of Plate 4"
Brinell No 130
0
1.0
2.0
3.0
4.0
5.0
Unit Lateral Flow in 1000 Strokes, in Thousandths

Fig. 24b
Longitudinal Flow of Plate
Due to Rolling
Diameter of Roller 8"
Test H 3A



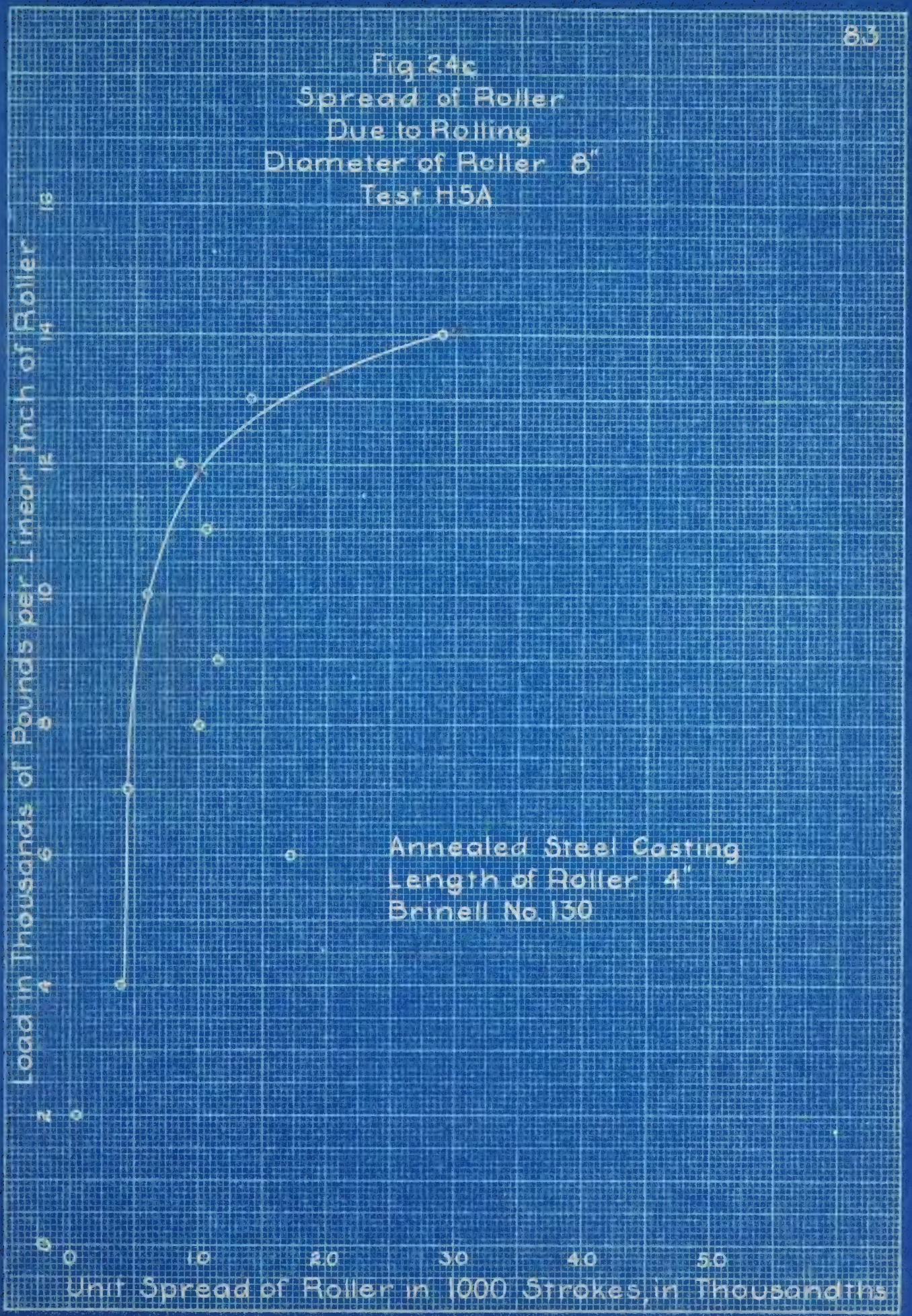


Fig 24c
Spread of Roller
Due to Rolling
Diameter of Roller 8"
Test H5A
Load in Thousands of Pounds per Linear Inch of Roller
0
2
4
6
8
10
12
14
16
Annealed Steel Casting
Length of Roller 4"
Brinell No. 130
0
10
20
30
40
50
Unit Spread of Roller in 1000 Strokes, in Thousandths

<u>6 Inch Roller on H9.</u> The load-deformation curves of this test are given in Fig. 25.

The critical load determined from the lateral flow is 9,500 pounds per inch width of plate. No interpretation was made from the data for spread of roller.

The curve of longitudinal flow indicates neither a reversal of curvature nor a break.

Fig 25a
Lateral Flow of Plate
Due to Rolling
Diameter of Roller 6"
Test H 9

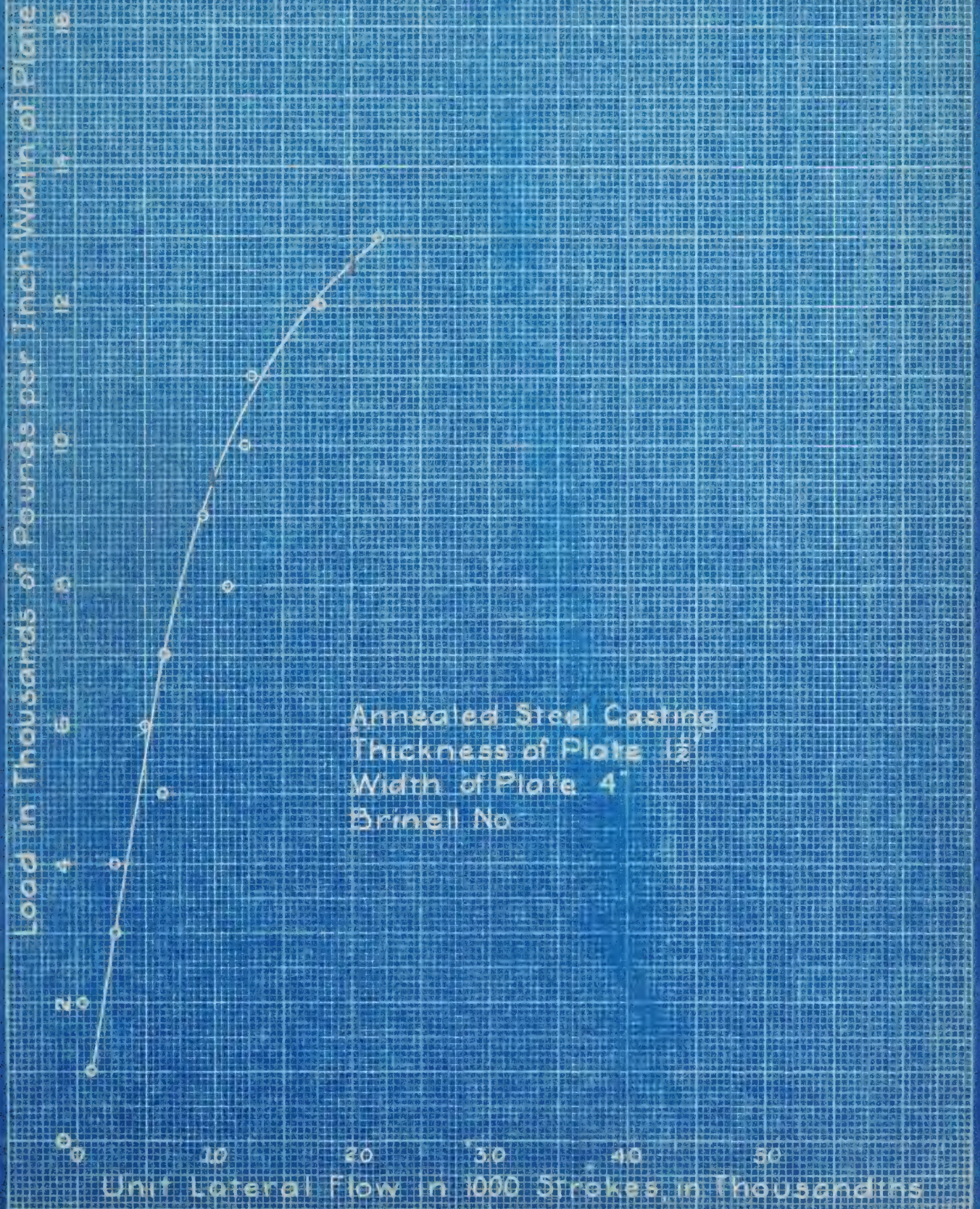


Fig 25 b
Longitudinal Flow of Plate
Due to Rolling
Diameter of Roller 6"
Test H9

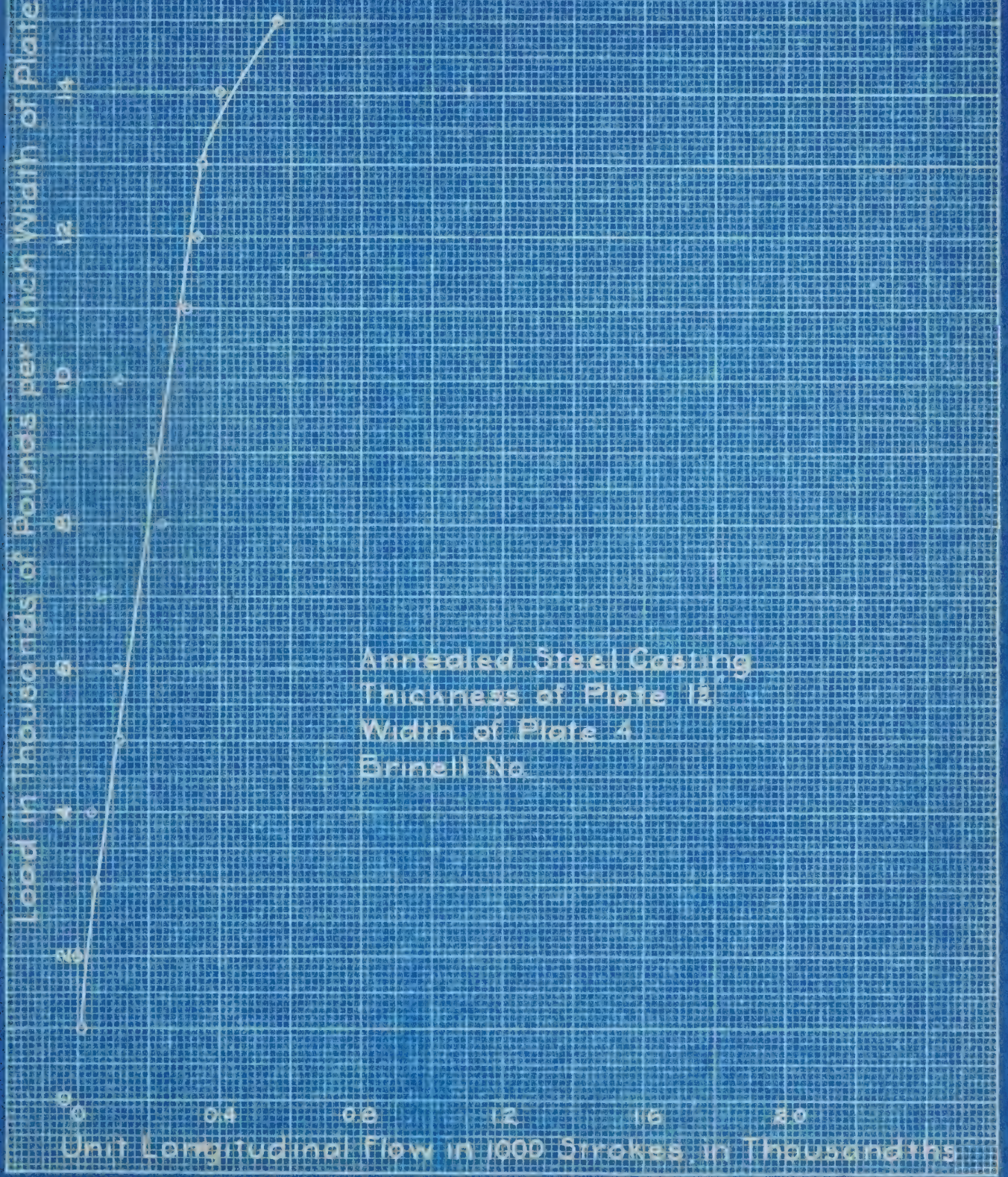


Fig 35c
Spread of Roller
Due to Rolling
Diameter of Roller 6"
Test No.

<u>4 Inch Roller on H7.</u> The load-deformation curves of this test are given in Fig. 26.

The critical load determined from the lateral flow of plate is 11,700 pounds per inch width of plate and from the spread of roller it is 11,000 pounds per linear inch of roller.

The curve of longitudinal flow indicates neither a break nor a reversal of curvature.

Fig 26a
Lateral Flow of Plate
Due to Rolling
Diameter of Roller 4"
Test H7

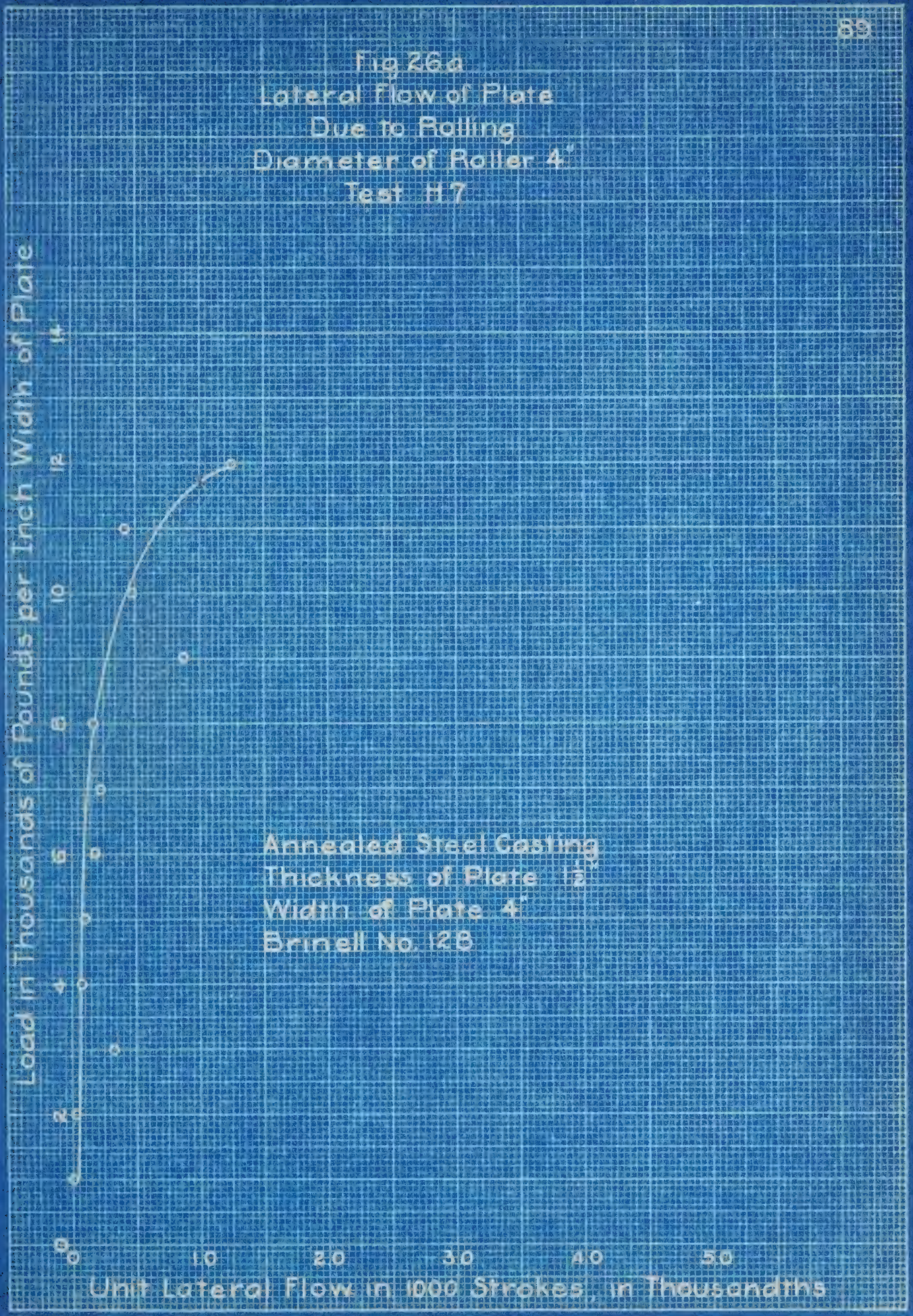
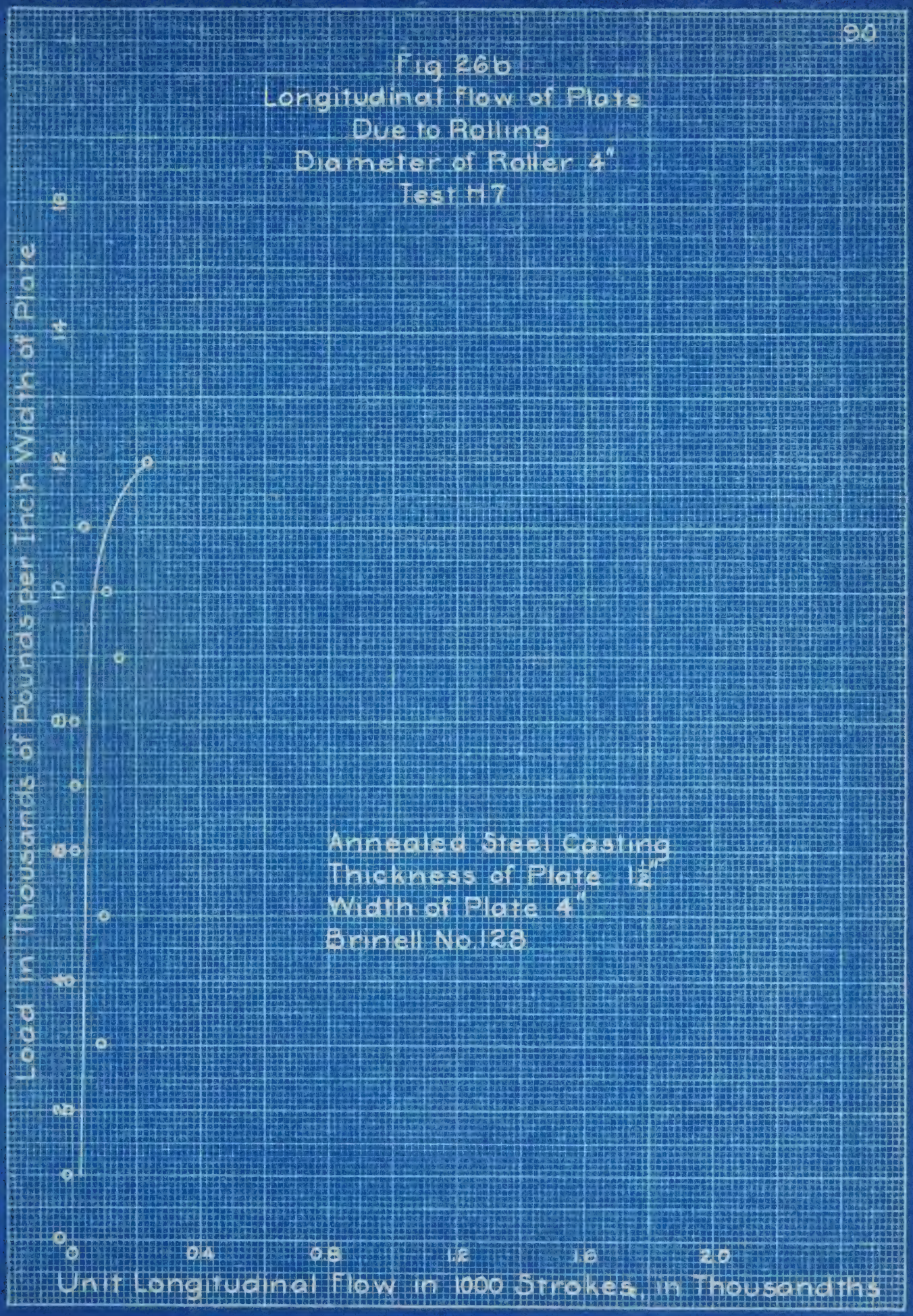


Fig 26b
Longitudinal Flow of Plate
Due to Rolling
Diameter of Roller 4"
Test H7



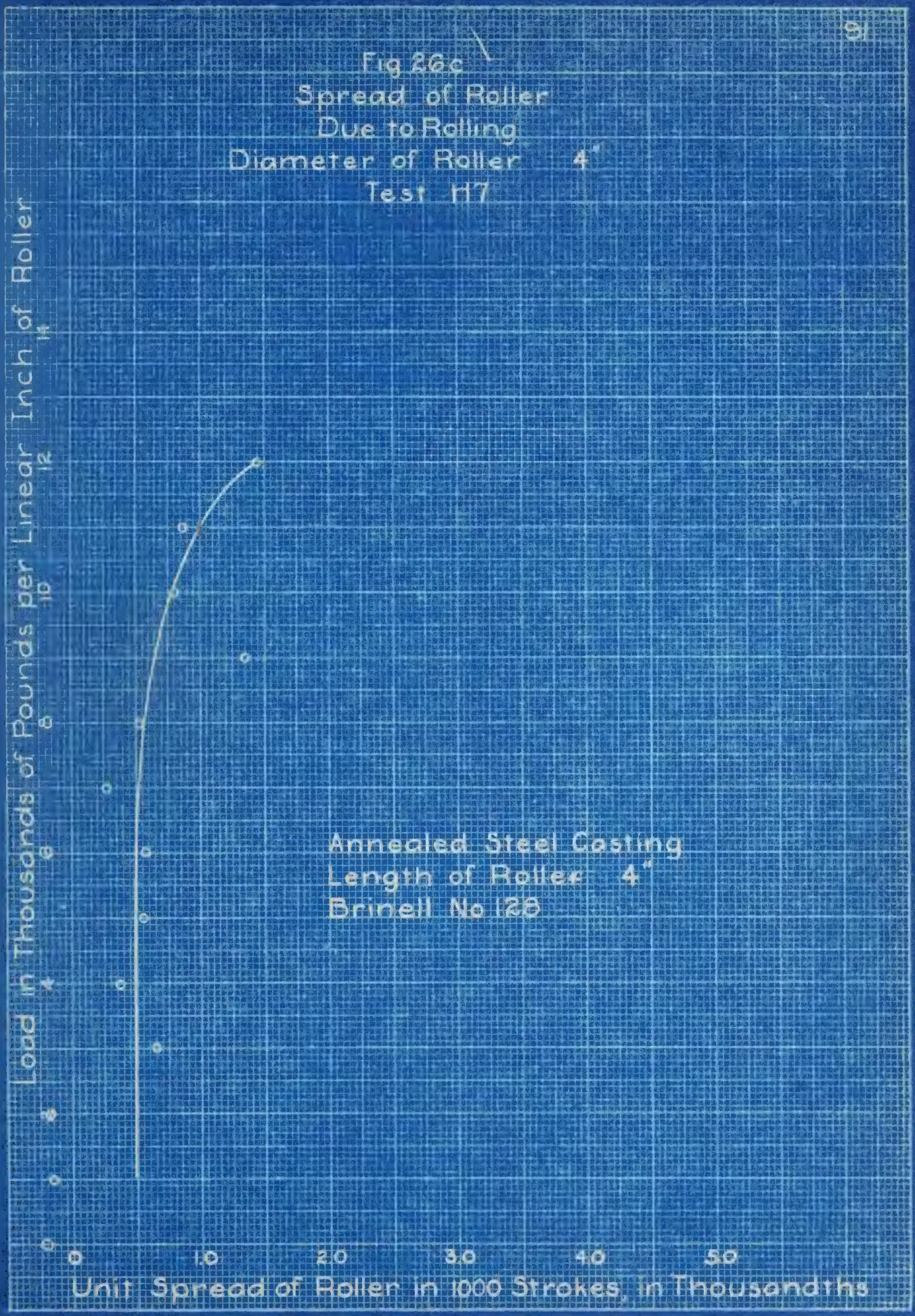


Fig 26c
Spread of Roller
Due to Rolling
Diameter of Roller 4"
Test H7
Annealed Steel Casting
Length of Roller 4"
Brinell No 128
Load in Thousands of Pounds per Linear Inch of Roller
0
2
4
6
8
10
12
14
0
1.0
2.0
3.0
4.0
5.0
Unit Spread of Roller in 1000 Strokes, in Thousandths

2 Inch Roller on H7A. It was impossible to measure the spread of roller in this test because the ends of the specimen rubbed on the guides in the lower side of the carriage. It was thought that the carriage might slide instead of roll on the specimen after the plate suffered some deformation; so it was watched carefully and did not slide.

The load-deformation curves of this test are given in Fig. 37.

Critical load determined from the lateral flow is 10,100 pounds per inch width of plate.

The longitudinal flow indicates neither a break nor a reversal of curvature.

Fig. 27a

Lateral Flow of Plate
Due to Rolling
Diameter of Roller 2"
Test H 7A

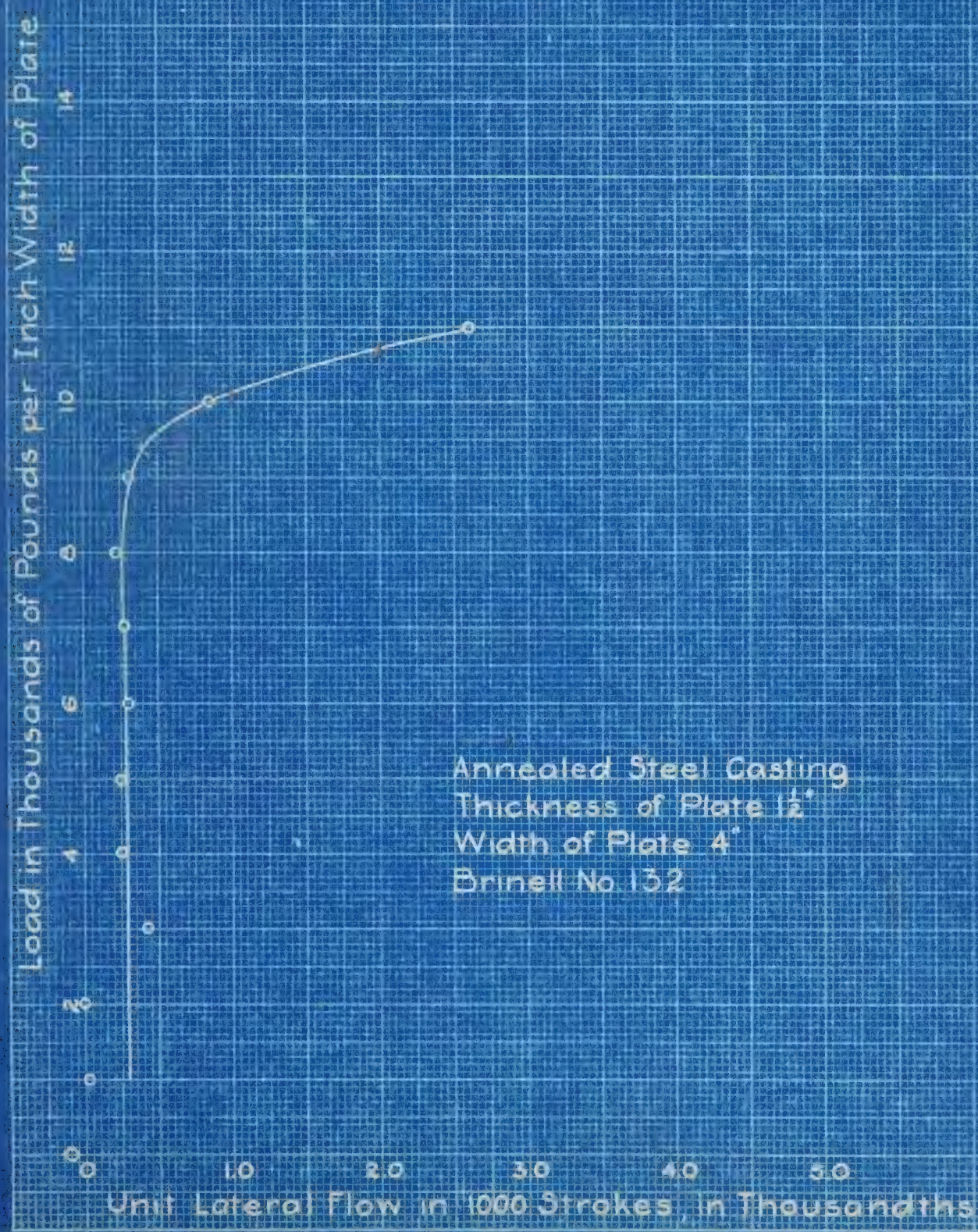


Fig 27 b
Longitudinal Flow of Plate
Due to Rolling
Diameter of Roller 2"
Test H7A

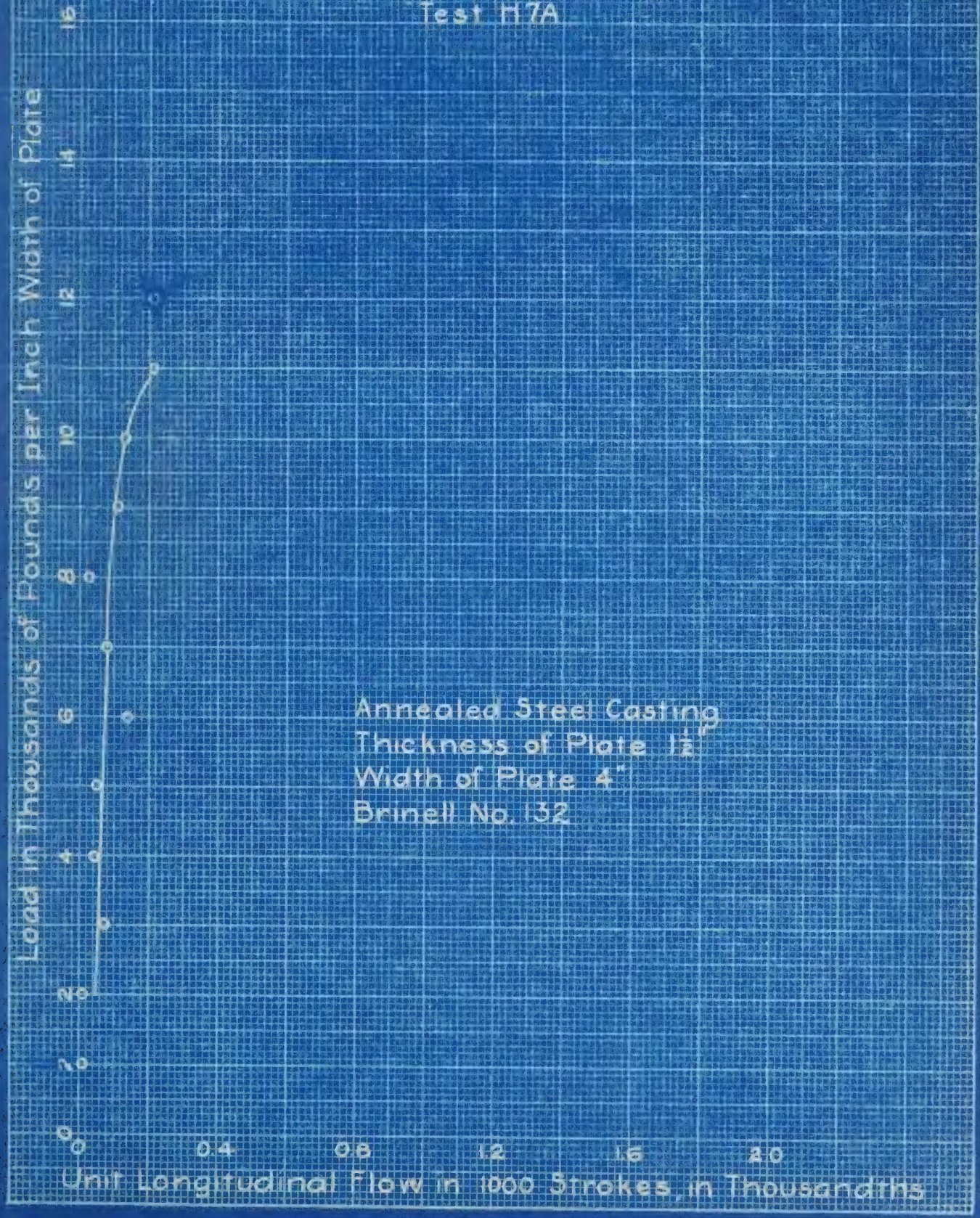


Table 2

Critical Loads
Rolling Tests of Small Rollers

Specimen	Diameter of Roller	Critical Load		
		Lateral Flow	Longitudinal Flow	Spread of Roller
H7A	2	10 100	——	——
H7	4	11 700	——	11 000
H9	6	9 500	——	——
H5A	8	10 600	——	11 900
H3A	10	10 100	12 000	11 400
H3	12	14 500	15 700	8 200
H5	16	15 200	13 300	14 900
H2	23½	21 600	22 000	21 800
H1	23½	21 800	21 100	22 500
H13	36	21 700	19 800	——
H12	68	22 100	30 000	——
H11	92	29 300	30 000	——
H10	116	34 500	33 300	——
H14	116	34 000	33 000	——

3. Discussion. The critical loads as determined by the methods described on page 34 are given in Tables 2&3. The values of the critical loads for rollers larger than 116 inch in diameter are taken from Professor Wilson's tests on large rollers as reported in Table 9 of Bulletin 191 of the Engineering Experiment Station of the University of Illinois.

In the discussion that follows, the value of the critical load is that determined by the lateral flow of plate and is the load at which the lateral flow is 0.001 of an inch per inch.

The writer has developed the equation of a line that approximates the experimental values very closely. It is

$$P = \left(\frac{p - 13000}{23000}\right)\left(3360\sqrt{D}\right)$$

where P is the critical load in pounds per inch width of plate, p is the yield point strength of the material in tension in pounds per square inch and D is the diameter of the roller in inches.

The writer was influenced in developing this equation by the equations proposed by:

Professor Wilson, $P = \left(\frac{p - 13000}{23000}\right)(18000 + 130D)$, where P is the critical load in pounds per inch width of plate, p is the yield point strength of the material in tension and D is the diameter of the roller in inches.

Messrs. Brown and Hartmann, $P = (4000 + 12D)\sqrt[3]{D}$ where P and D are as defined above.

The effect of the yield point strength of the material was studied by Professor Wilson. The factor $\left(\frac{p - 13000}{23000}\right)$ seems to take care of the effect of the properties of the material very well.

The line representing the equation developed by the author is compared with the experimental data in Figure 28a and Figure 28b, the latter being a large scale diagram for rollers less than 36 inches in diameter.

The design formula for the safe load on a steel roller should give values less than those determined as critical loads in this investigation. A factor of safety of 3/2 is not thought too conservative. The formula for the safe load on steel rollers of medium grade steel casting recommended by the author is

$$P = \left(\frac{p - 13000}{23000}\right)\left(3440\sqrt{D}\right),$$

where P is the safe load in pounds per inch width of plate, p is the yield point strength of the material in tension and D is the diameter of the roller in inches.

It is an open question whether or not smaller loads than these values of the critical load would have produced excessive flow had these plates not suffered some cold working by being rolled at smaller loads. The critical load for the 10 inch roller is 10,100 pounds per inch width of plate and is next the smallest of the entire series. That block received less cold working than any other specimen, having been rolled only 4000 strokes at various loads when the critical load was reached. The 8 inch roller with a critical load of 10,600 pounds per inch of width received 7000 strokes at various loads less than the critical load.

An effect of rolling is to increase the hardness of the specimen. The Brinell number for the rolled portion is several points higher than for the unrolled portion. Rolling seems to

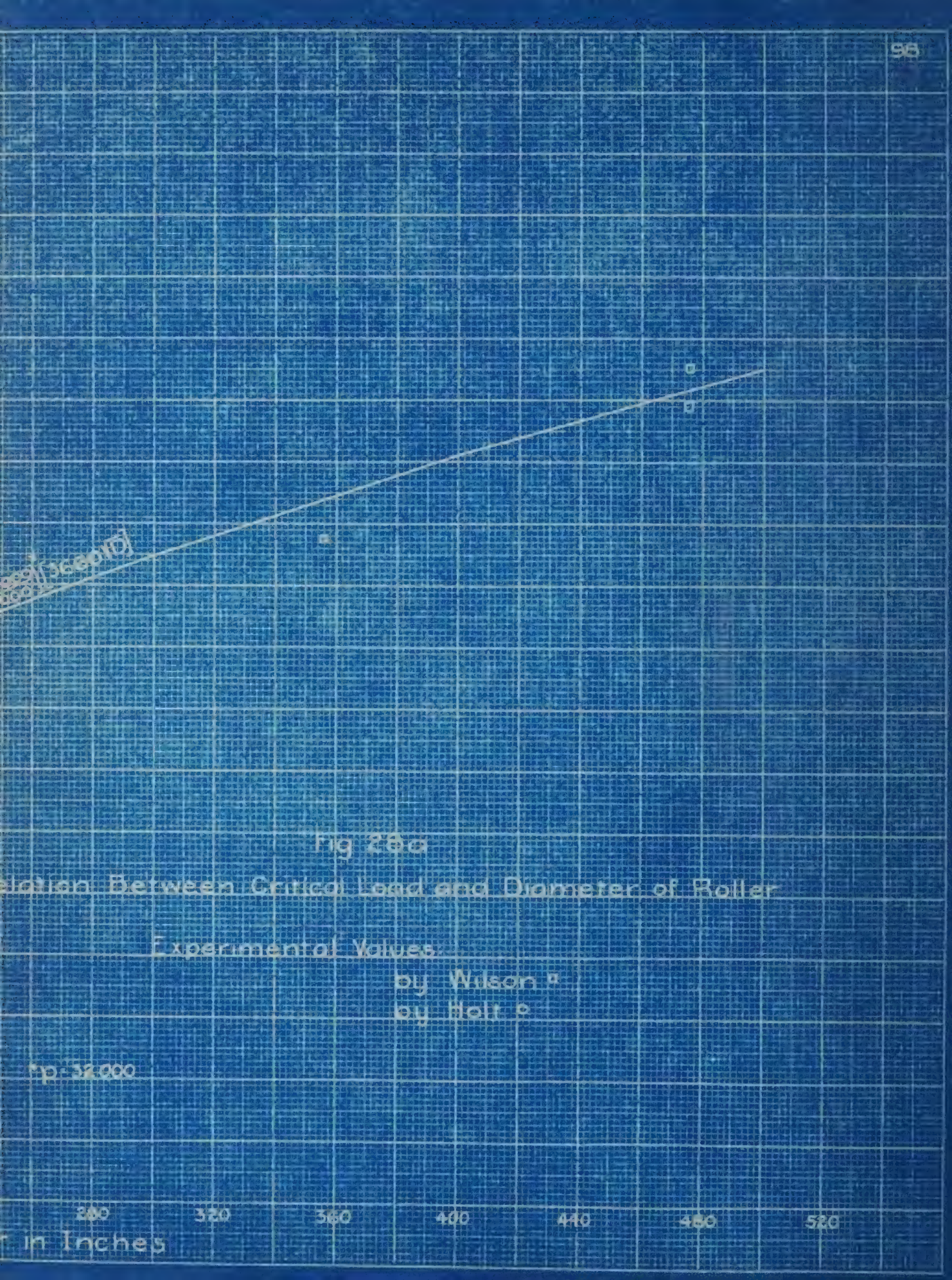
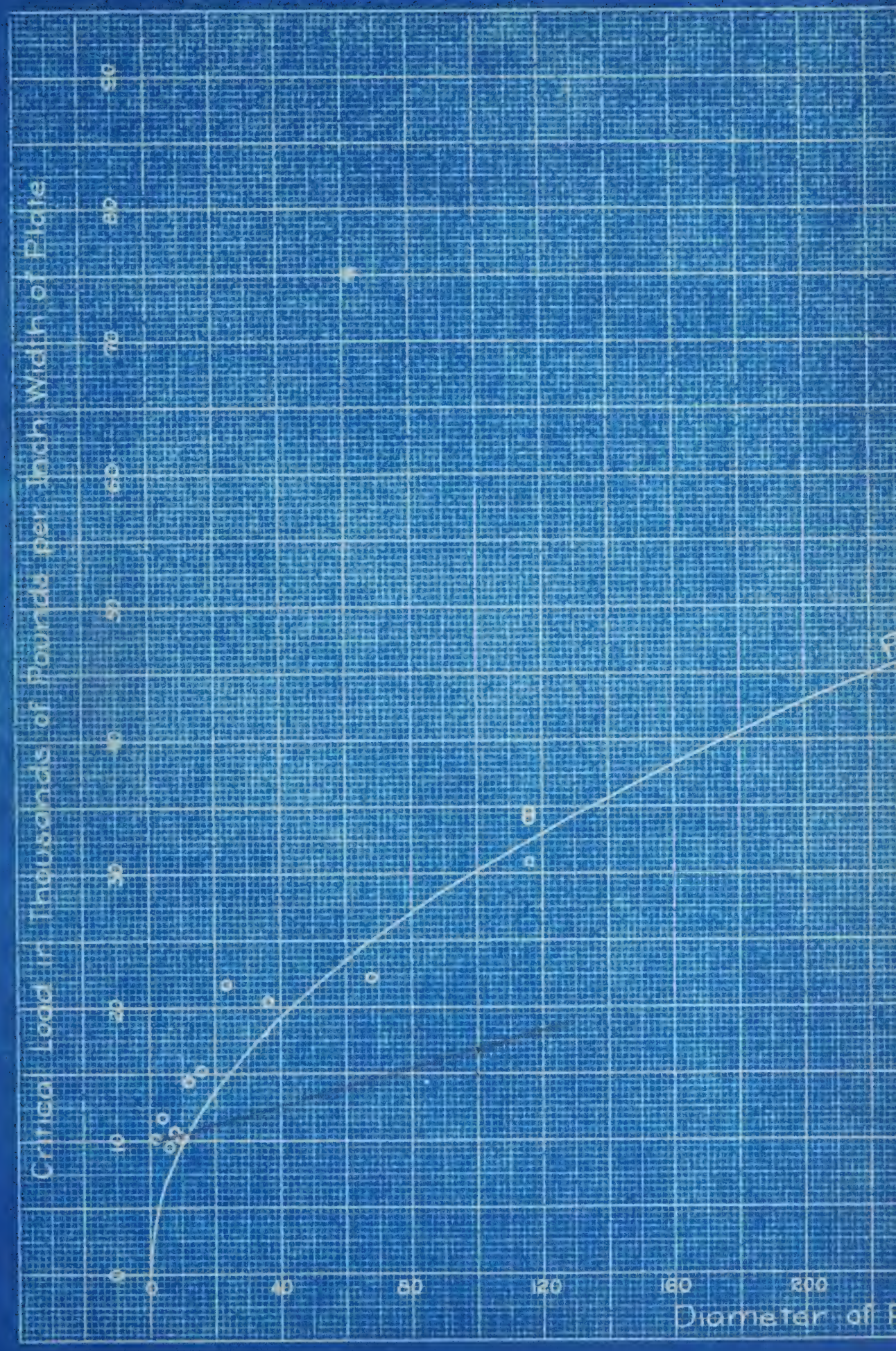


Fig 26a
elation Between Critical Load and Diameter of Roller
Experimental Values
by Wilson
by Holt
Mp=32,000
280
320
360
400
440
480
520
r in Inches


Critical Load in Thousands of Pounds per Inch Width of Plate
0
10
20
30
40
50
60
70
80
90
0
40
80
120
160
200
Diameter of P

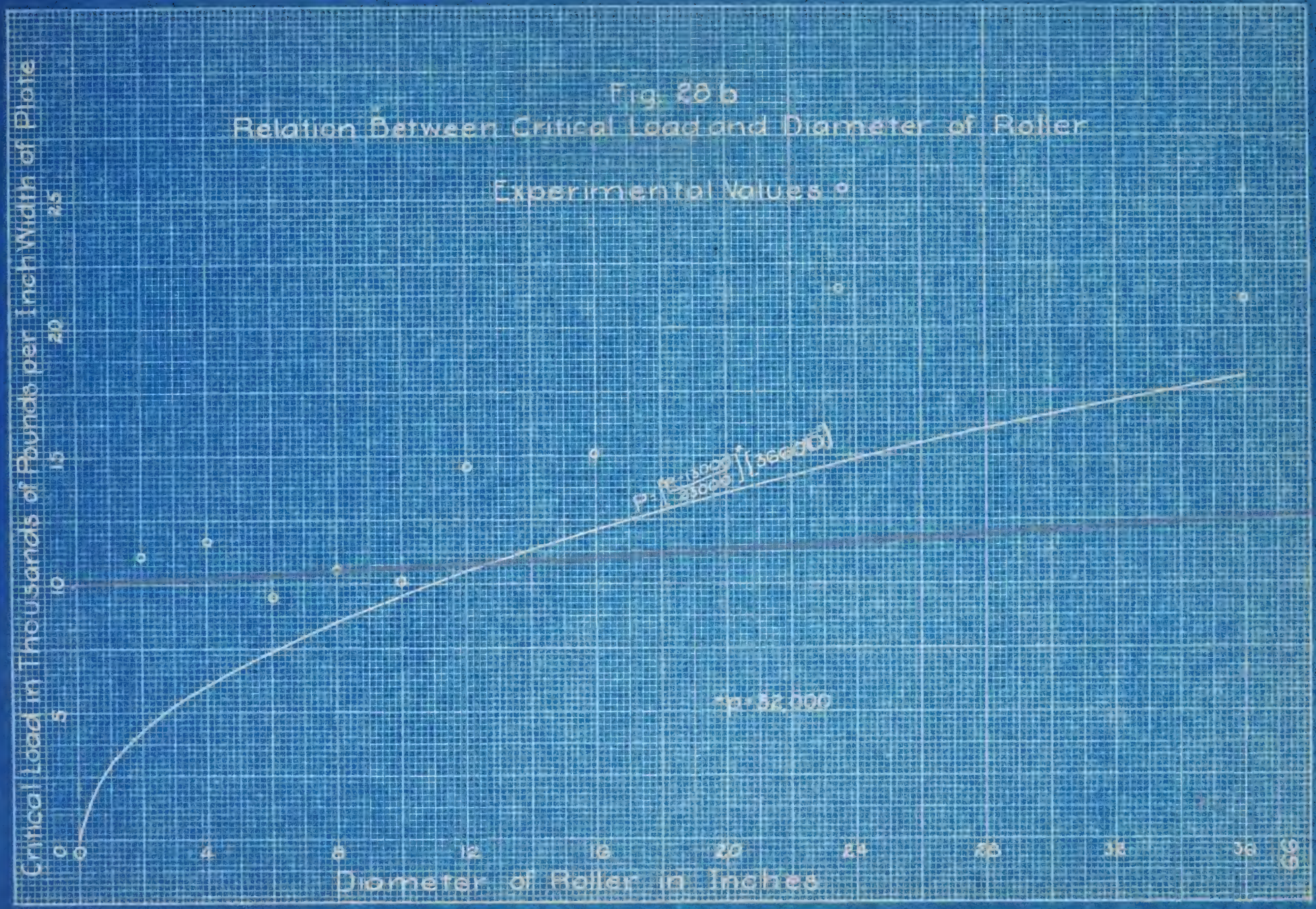


Fig. 28 b
Relation Between Critical Load and Diameter of Roller
Experimental Values
Critical Load in Thousands of Pounds per Inch Width of Plate
Diameter of Roller in Inches
0
5
10
15
20
25
0
4
8
12
16
20
24
28
32
36
40
50

have increased the hardness of the specimen through its entire depth, the unrolled portion of H5A and H7A having a higher Brinell number than H5 and H7 respectively.

VIII. Comparison with Results of Others.

VIII. COMPARISON WITH RESULTS OF OTHERS.

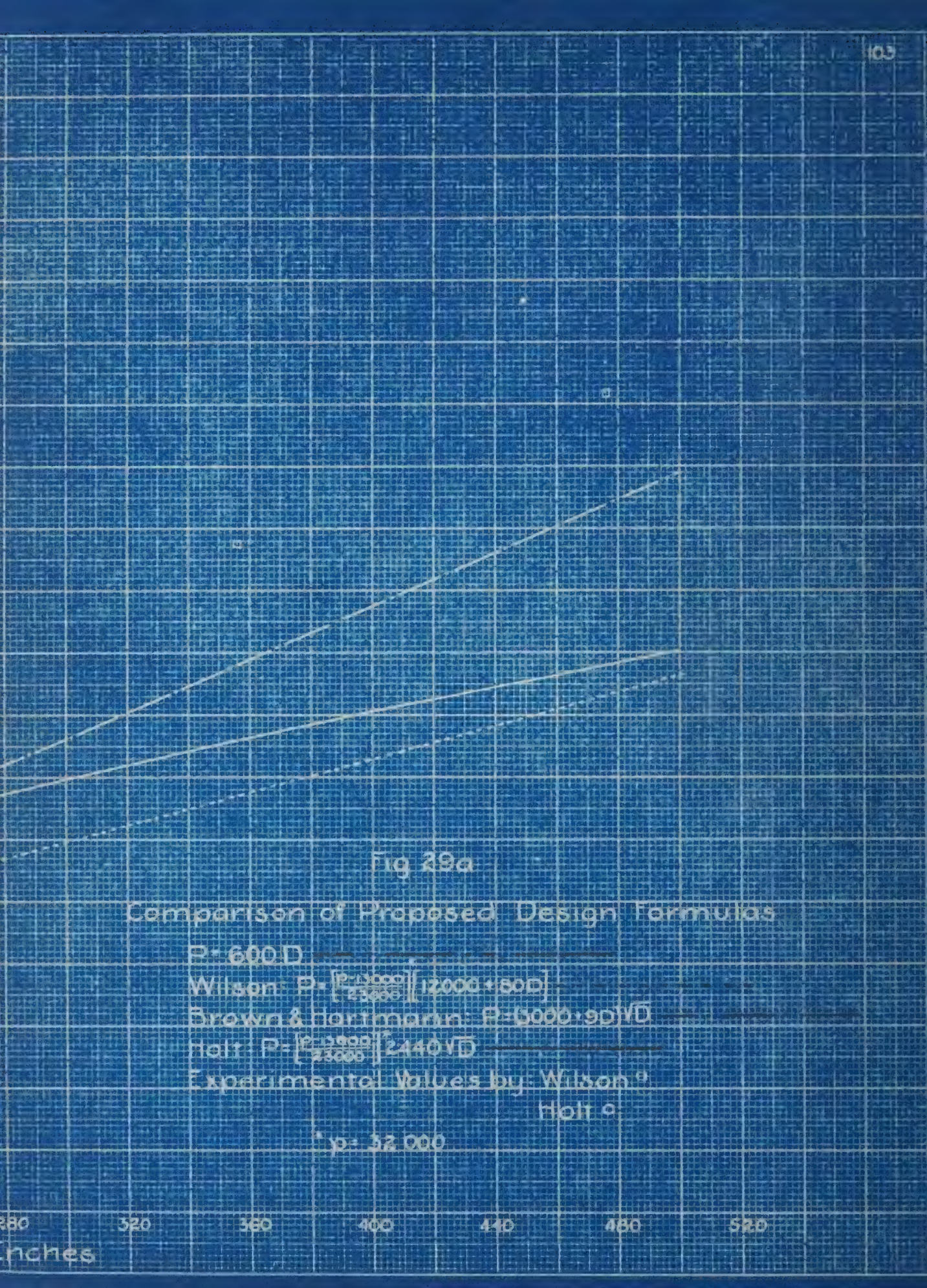
1. Discussion. The author's design formula and the design formulae proposed by other writers are compared in Figure 29.

It is seen from Figure 29b that the formula P = 600D gives values of the design load that are dangerously great for values of D greater than 24 inches.

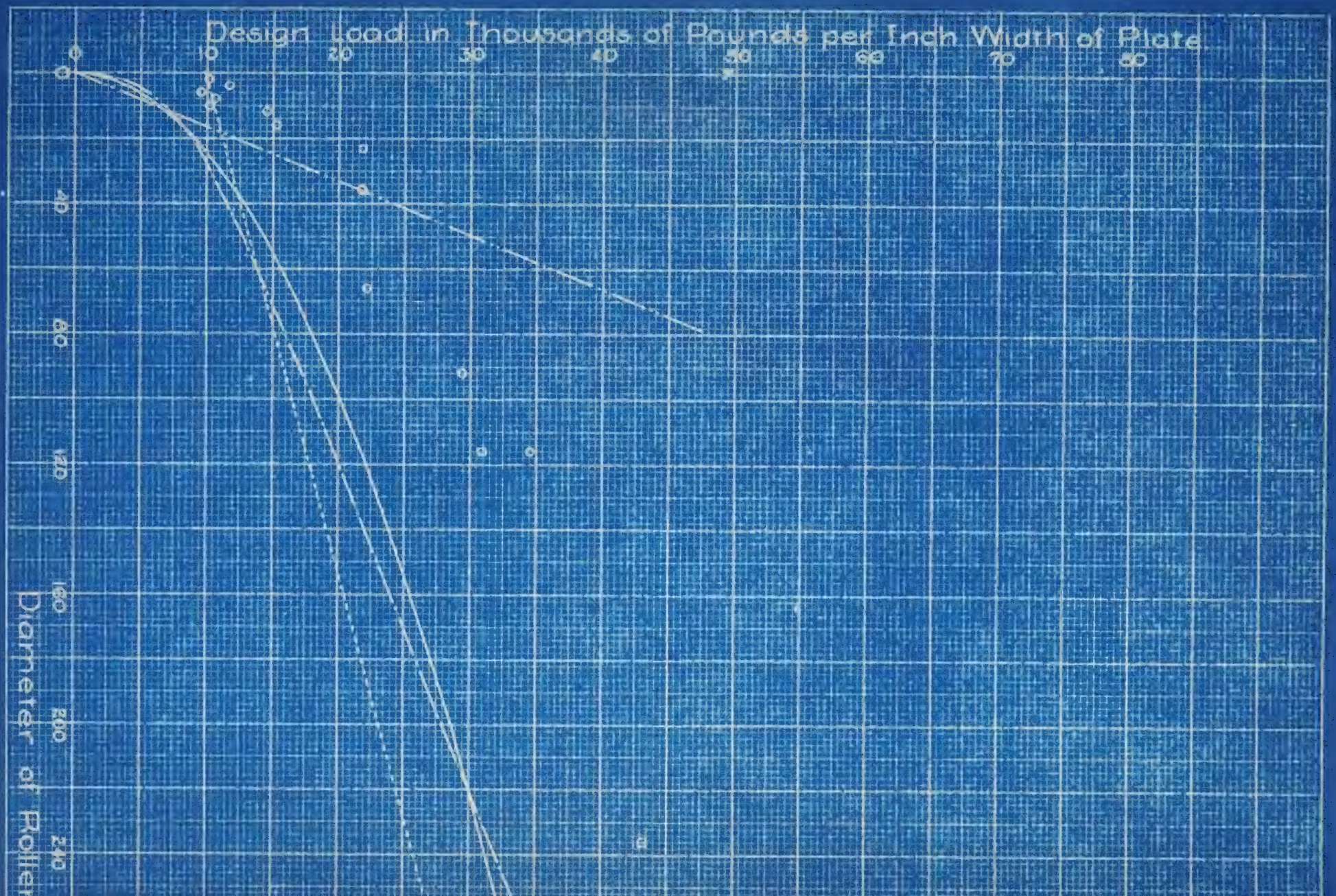
The author's design formula allows higher working loads than the formulae of Professor Wilson, and Messrs. Brown and Hartmann for diameters from 38 inches to 220 inches. For diameters greater than 220 inches the author's design formula gives values greater than the formula of Professor Wilson and less than allowed by Messrs. Brown and Hartmann. The use of any of the three proposed formulae will give loads that can be safely rolled on a plate of medium grade steel casting having a rectangular cross-section.

Table 3 gives a comparison of the design load with the experimentally determined critical load. The values of the critical load for tests not performed in this investigation are taken from Table 9, Bulletin 191 Engineering Experiment Station of the University of Illinois. They were determined in the manner described in this thesis. All the plates had rectangular sections and were 1½ inches thick. The values of the critical load for the A and E series are small. The specimens were defective in that they had blow holes along their vertical centerline. Test H14 of this series was similar to the F series reported here. The critical load from the lateral flow of Test H14 is 34000 pounds per inch width of plate while from the E series it is only 25,400

pounds per inch of width. The proposed design load for rollers 2 inches or 4 inches in diameter are probably very conservative.


103
Fig 29a
Comparison of Proposed Design Formulas
P=600D
Wilson: P=[P-13000/23000][12000+80D]
Brown & Hartmann: P=(3000+9D)√D
Holt: P=[P-13000/23000]²2440√D
Experimental Values by: Wilson ⊕
Holt ⊖
*p=32,000
280
320
360
400
440
480
520
Inches

ENGRAVING 334 - 8½ 10 X 10 TO THE HALF INCH
WHEN ORDERING STATE COLOR, DRAWING OR TRACING PAPER OR CLOTH



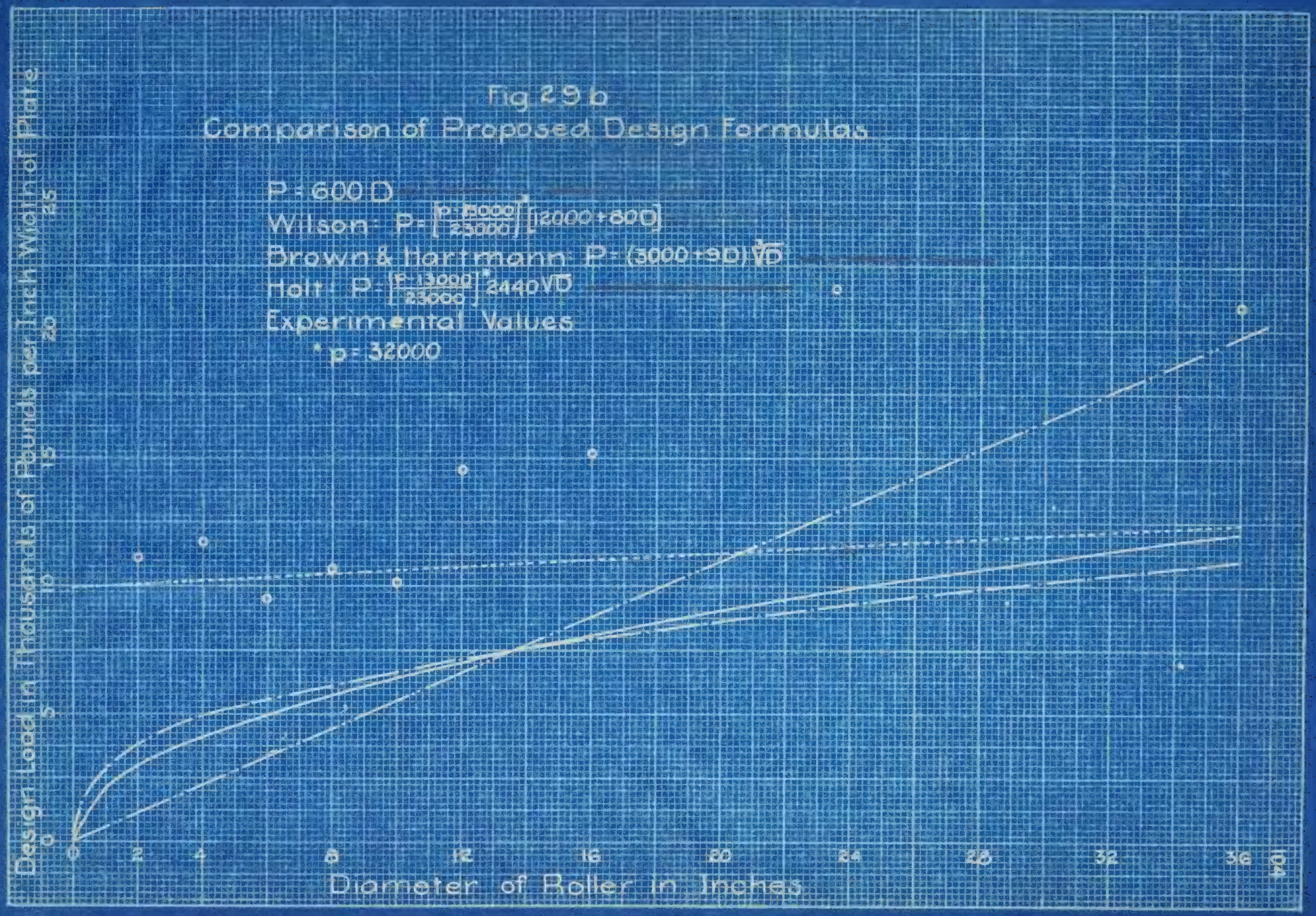


Fig 29 b
Comparison of Proposed Design Formulas
P = 600 D
Wilson: P = [p - 15000 / 23000] * [12000 + 600]
Brown & Hartmann: P = (3000 + 9D) * √D
Holt: P = [p - 13000 / 23000] * 2440 √D
Experimental Values
* p = 32000
Design Load in Thousands of Pounds per Inch Width of Plate
0
5
10
15
20
25
0
2
4
8
12
16
20
24
28
32
36
40
Diameter of Roller in Inches

Table 3

Comparison of Proposed Design Load with Experimentally Determined Critical Load

Series	Diameter	Yield Point	Design Load	Critical Load from Lateral Flex	Critical Load from Longitudin Flex	% Design Load of Critical Load
H	2	32,060	2860	10,100		28
	4	32,060	4050	11,700		34
	6	33,600	5350	9,500		56
	8	32,790	5950	10,600		56
	10	31,880	6340	10,100	12,000	63
	12	31,880	6950	14,500	15,700	53
	16	32,790	8400	15,200	13,300	55
	23½	32,500	10,000	21,600	21,500	46
	36	30,760	11,300	[illegible]	[illegible]	[illegible]
	68	30,920	15,700	22,100	30,000	71
	92	30,800	18,200	29,300		62
	116	31,500	22,300	34,250	33,150	65
E	116	34,533	24,400	25,400	30,700	
A	188	30,869	26,000	24,050	29,650	
F	116	31,900	21,600	31,000	32,000	70
	236	32,600	32,000	43,000	42,500	74
	356	31,200	36,400	54,300	52,700	67
	476	31,900	43,800	66,000	63,300	67
F Hardened	236	56,000	70,000	80,000	70,000	88
	356	57,023	88,200	105,000	100,000	84
	476	56,500	100,100	144,500	142,500	70
L	116	31,377	21,000	22,500	24,000	93
	236	23,664	17,300	19,900	22,250	87
	356	"	21,200	28,950	28,850	73
	476	"	24,600	31,000	30,975	79
LA	116	45,631	37,300	47,200	45,550	79
	236	45,380	52,700	73,750	63,750	72
	356	46,685	67,500	88,750	82,250	76
M	356	31,219	38,500	51,500	47,500	75
C	236	43,505	49,800	59,500	61,000	84
HYLC	236	57,663	72,800	105,000	106,000	69

IX. CONCLUSIONS.

IX. CONCLUSIONS.

1. Conclusions. The tests upon which these conclusions are based were made on rollers varying in diameter from 2 inches to 476 inches and on plates of medium grade steel casting 1½ inches thick having a rectangular cross-section. The conclusions are as follows:

a. During rolling there is a flow of metal in the plate in the direction of and normal to the plane of rolling.

b. When the plate and roller are made of similar material there is a flow of metal in the roller in the direction of its axis.

c. The hardness of the material, indicated by the Brinell hardness test, is greater after a rolling test than before.

d. The design formula P = 600D gives values which are too small for rollers less than 14 inches in diameter and dangerously great for rollers larger than 24 inches in diameter.

e. The experiments justify the use of the following formula for the design of rollers bearing on plates of medium grade steel casting having a rectangular cross-section and a thickness of 1½ inches or more;

$$P = \left(\frac{p - 13000}{23000}\right)\left(2440\sqrt{D}\right)$$

where P is the design load in pounds per inch width of plate, p is the yield point strength of the material in tension, and D is the diameter of the roller in inches.

f. The use of any of the three proposed design formulae* give results that can be safely rolled on plates of medium grade steel

*Formulae by Wilson, Brown and Hartmann, and Holt.

casting having a rectangular cross-section and a thickness not less than $1\frac{1}{2}$ inches. However, the author's formula approximates the experimentally determined critical loads more closely than either of the others.

PART II.

ADDITIONAL STUDIES.

PART II.

I. THE EFFECT OF THICKNESS OF PLATE ON THE CRITICAL LOAD.

PART II. ADDITIONAL STUDIES.

I. THE EFFECT OF THICKNESS OF PLATE ON THE CRITICAL LOAD.

1. Foreword. Professor Wilson made five series of tests to determine a relation between the thickness of plate and the critical load. The thicknesses studied varied from ½ inch to 4 inches and the diameter of roller varied from 118 inches to 476 inches. The relation between the critical load from longitudinal flow and thickness of plate was found to be constant for the range of thicknesses studied. The only inconsistency was in the test of 4-inch plates rolled under a 476 inch roller. The load-deformation curves indicate that the longitudinal flow began at the top of the plate before it did at the bottom, the opposite of what occurred in the thinner plates. From that, it seems that the critical load from longitudinal flow governs as long as that flow first occurs at the bottom of the plate. The relation between critical load from lateral flow and thickness of plate was found to increase with the thickness, reach a maximum and decrease with a further increase in thickness.

The following discussion taken from Bulletin 191 of the Engineering Experiment Station may have some bearing on the relation between the thickness of plate and the critical load from lateral flow. The lateral flow is a maximum attthe rolled surface and decreases rapidly with the depth from the top. A thin plate has a tendency to flow throughout its entire depth while the highly stressed material in a deeper plate is reinforced by the under-

stressed material just below. At the same time, the outside corner is supported entirely by the shearing resistance on an inclined plane. The portion of the specimen supported by the shear on inclined planes increases with the depth but at a decreasing rate. The result is a combination of the two effects.

The purpose of this series was to study the effect of the thickness of plate through a wide range.

8. Description of Test. The plate was a portion of a medium grade steel casting which had been annealed. It was from the same heat as the other specimens for rolling tests. A large blow-hole extended through the plate along its vertical center line. The chemical properties are: C, 0.283; S, 0.045; Si, 0.046; Mn, 0.496. The physical properties determined from standard tensile tests are given in Table IV .

At the beginning of the test, the plate was 8½ inches thick. After each test, the rolled portion was cut off, the plate refinished and tested again. The thicknesses of plate tested were 8½ inches, 7¼ inches, 6 inches, 4¾ inches, 3¾ inches, 2¾ inches, 1-3/8 inches. The portion removed was at least 1 inch thick and thought thick enough to remove all the metal which had received any permanent deformation. Tensile test specimens were cut from the portion removed. The specimen from the rolled portion was taken 2 inches from the lateral center line in order to avoid material adjacent to the defect. The specimen from the unrolled portion was taken ¾ inch from the end of the specimen.

Table 4

Physical Properties of Plates

Rolling Tests of Thick Plates

Specimen	Before Rolling					After Rolling				
	Ultimate Strength	Yield Point	Elongation in 2 inches	Reduction of Area	Brinell Number	Ultimate Strength	Yield Point	Elongation in 2 inches	Reduction of Area	Brinell Number
A17	67,430	30,880	22.60	25.70	139	67,090	36,390	11.80	11.30	142
A18	67,350	30,750	21.20	22.94	129	67,610	39,950	13.25	18.32	141
A19	67,340	30,330	21.69	22.30	131	65,290	31,200	13.62	14.96	141
A20	67,460	30,410	19.32	21.62	133	65,173	32,990	12.12	15.61	138
A21	67,020	30,390	19.32	22.27	135	65,357	32,130	12.83	14.84	144
A22	67,140	30,710	17.74	21.01	131	65,970	32,710	11.87	13.76	140
A23	67,140	30,020	19.00	21.47	127	64,697	32,247	13.00	17.01	140

The apparatus used for this series of tests was that used by Professor Wilson in his study of large rollers and is described on page 14. The diameter of roller was 116 inches.

The deformations were measured with the micrometer and strain gage described on page 21. The procedure of testing large rollers described on page 34 was followed in this series of tests, except that the specimens were rolled 3000 strokes at each load instead of 1000.

3. Results. The results of this study are given in the curves of Figures 30 to 36 inclusive.

In plates that are thick in proportion to the diameter, the critical load from lateral flow governs the bearing value while the critical load from longitudinal flow governs for thin plates. The thickness of plate which gives equal critical loads from lateral and longitudinal flow, as determined by Professor Wilson, is 1 inch + 0.004D which in this case is 1.46 inch. This is borne out by these tests in which the lateral flow governs in all cases except for the thinnest plate which is 1.37 inches thick.

The critical load is interpreted to be that load at which the lateral flow is 0.001 inches per inch in 3000 strokes.

The effect of rolling is to increase the Brinell number of the rolled portion. The effect of rolling at one thickness seems to have no effect on the hardness of the material at the depth of the next rolled surface. If the effect of rolling at one thickness had an effect on the hardness of the material throughout the block, the thinnest plate would be expected to have the largest Brinell number whereas it has the smallest.

Fig. 30a

Lateral Flow of
Annealed Steel Casting
Due to Rolling

Diameter of Roller 116"
Width of Plate 4"
Thickness of Plate $8\frac{1}{2}$"
Brinell No. 139
Test A17

Legend:
Flow $\frac{1}{8}$" from top of Plate ○
Flow $1\frac{1}{8}$" from top of Plate △
Flow $2\frac{1}{8}$" from top of Plate □

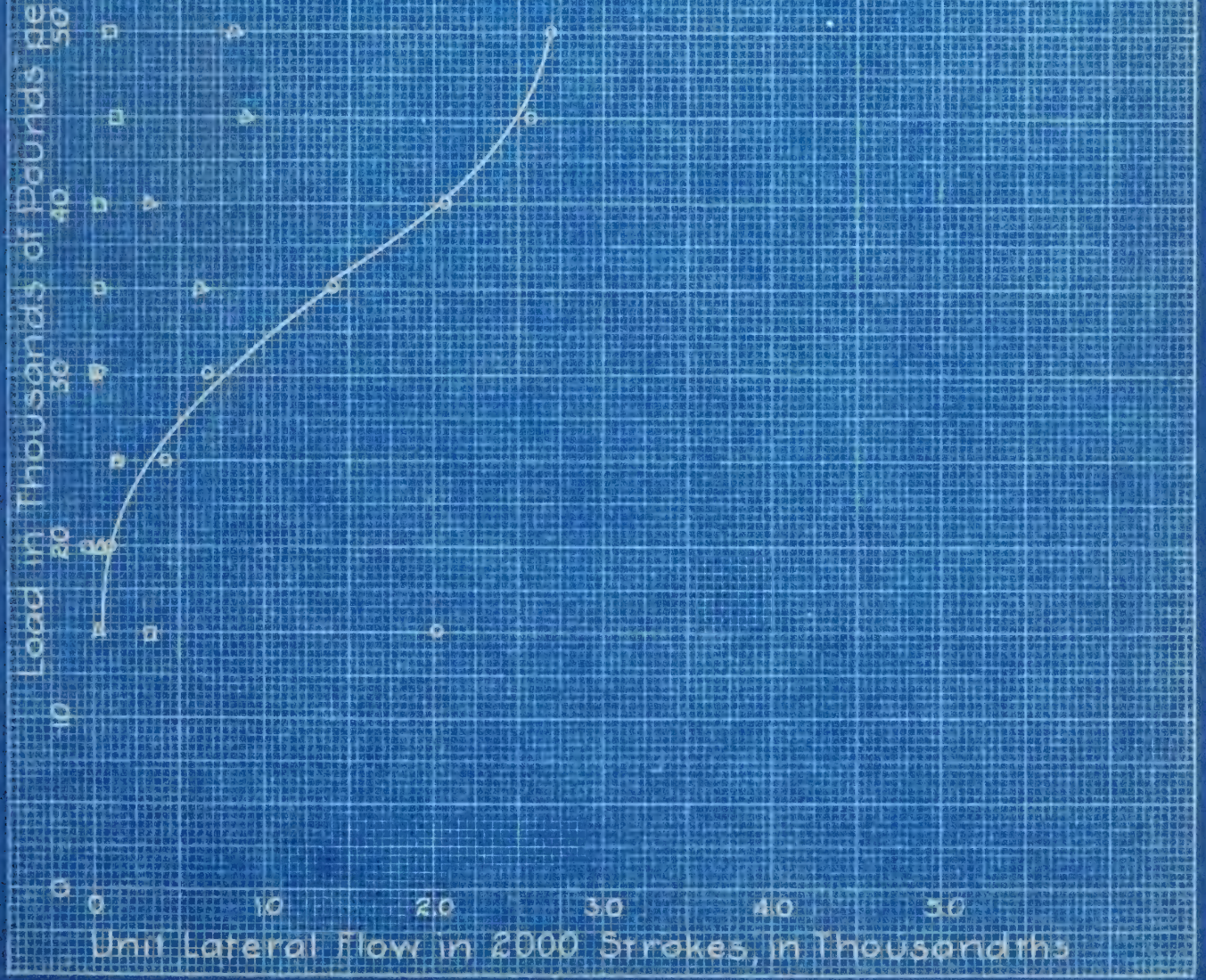


Fig. 31a

Lateral Flow of
Annealed Steel Casting
Due to Rolling

Diameter of Roller 16"
Width of Plate 4"
Thickness of Plate 7¼"
Brinell No. 129
Test A18

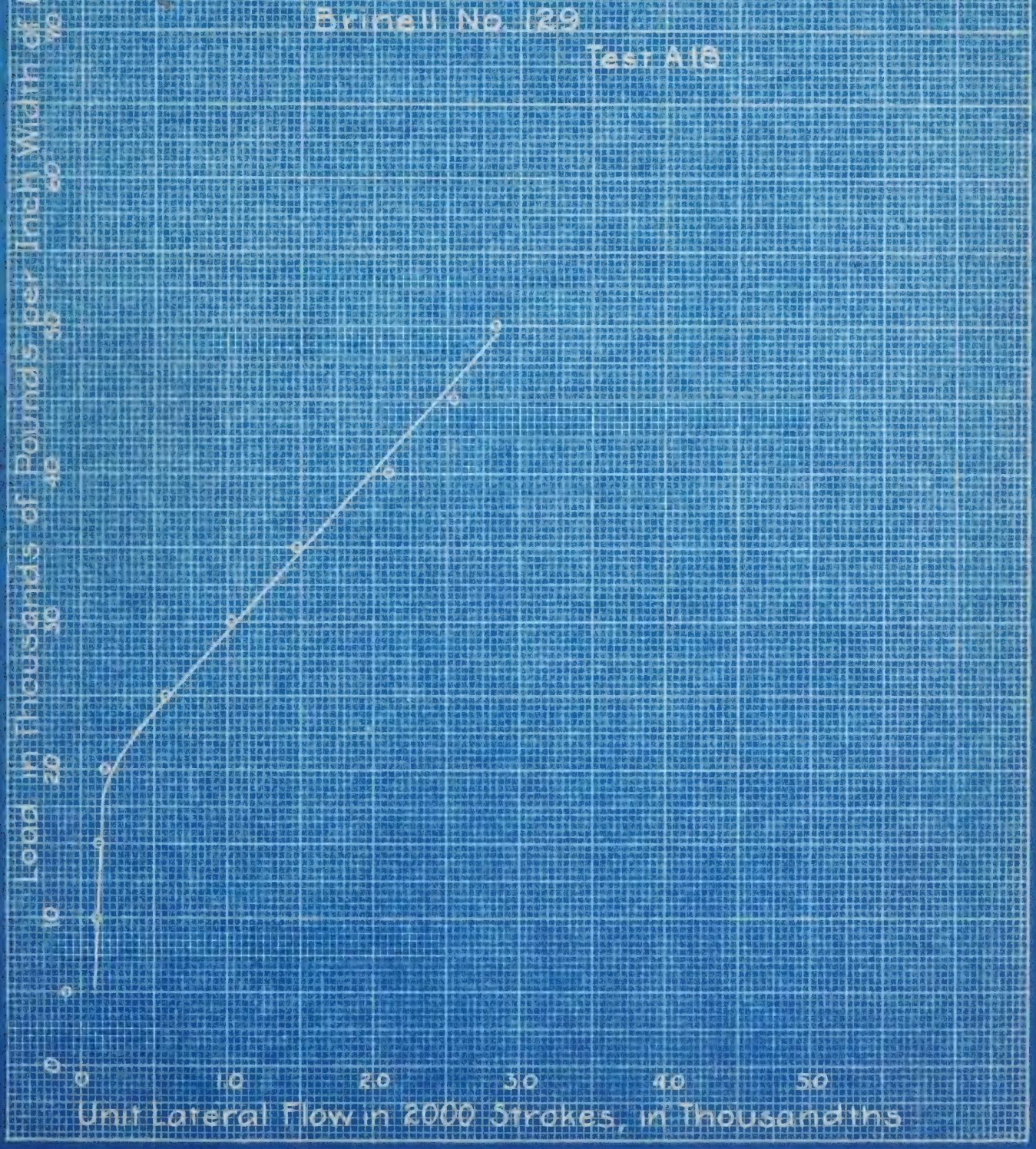


Fig 31b

Longitudinal Flow of
Annealed Steel Casting
Due to Rolling

Diameter of Roller 11.6"
Width of Plate 4"
Thickness of Plate 7¼"
Brinell No. 129
Test A16

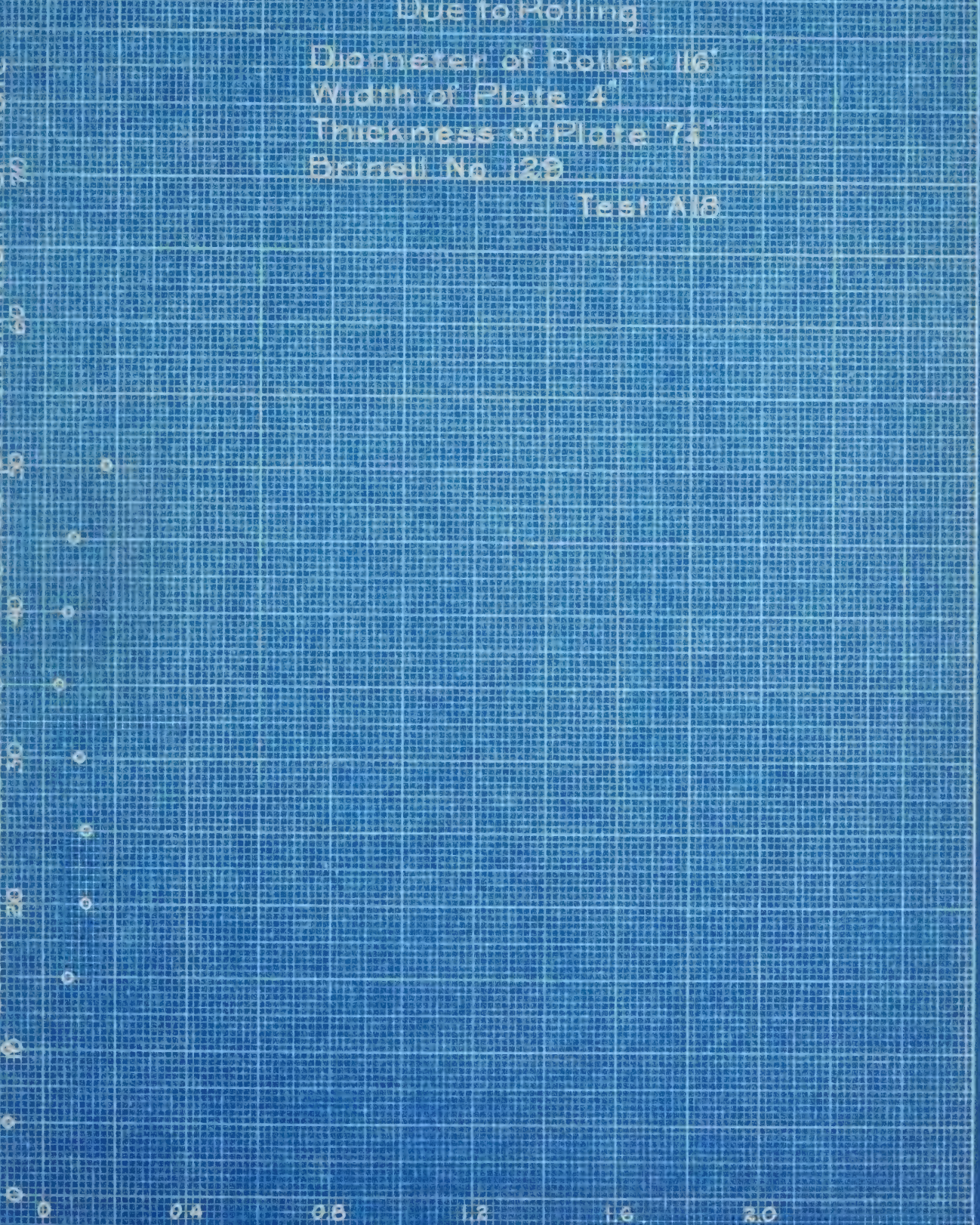


Fig 32a

Lateral Flow of
Annealed Steel Casting
Due to Rolling

Diameter of Roller 116"
Width of Plate 4"
Thickness of Plate 6"
Brinell No. 131

Test A19

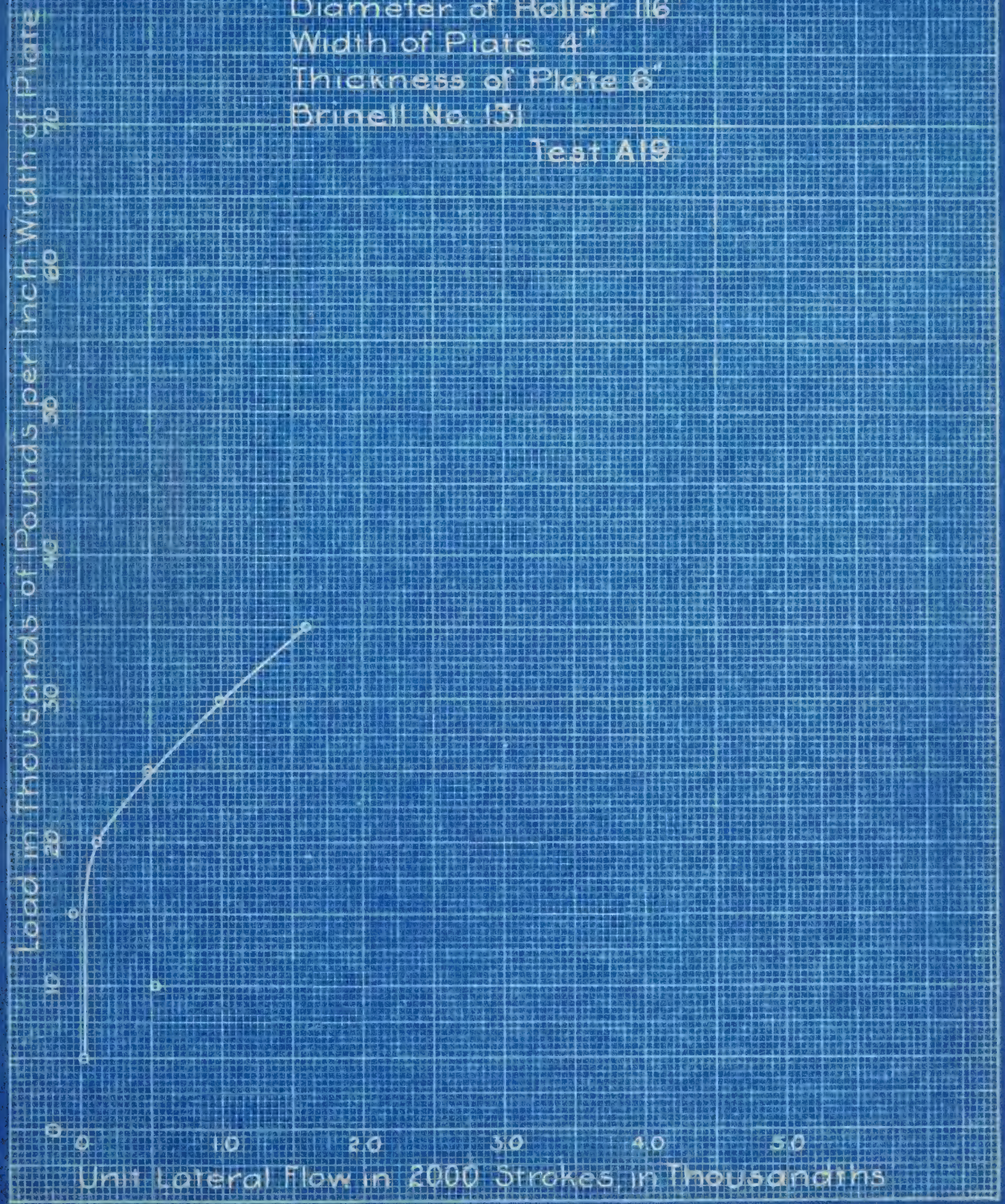


Fig. 32b

Longitudinal Flow of
Annealed Steel Casting
Due to Rolling

Diameter of Roller 16"
Width of Plate 4"
Thickness of Plate .75"
Brinell No. 151

Test A18

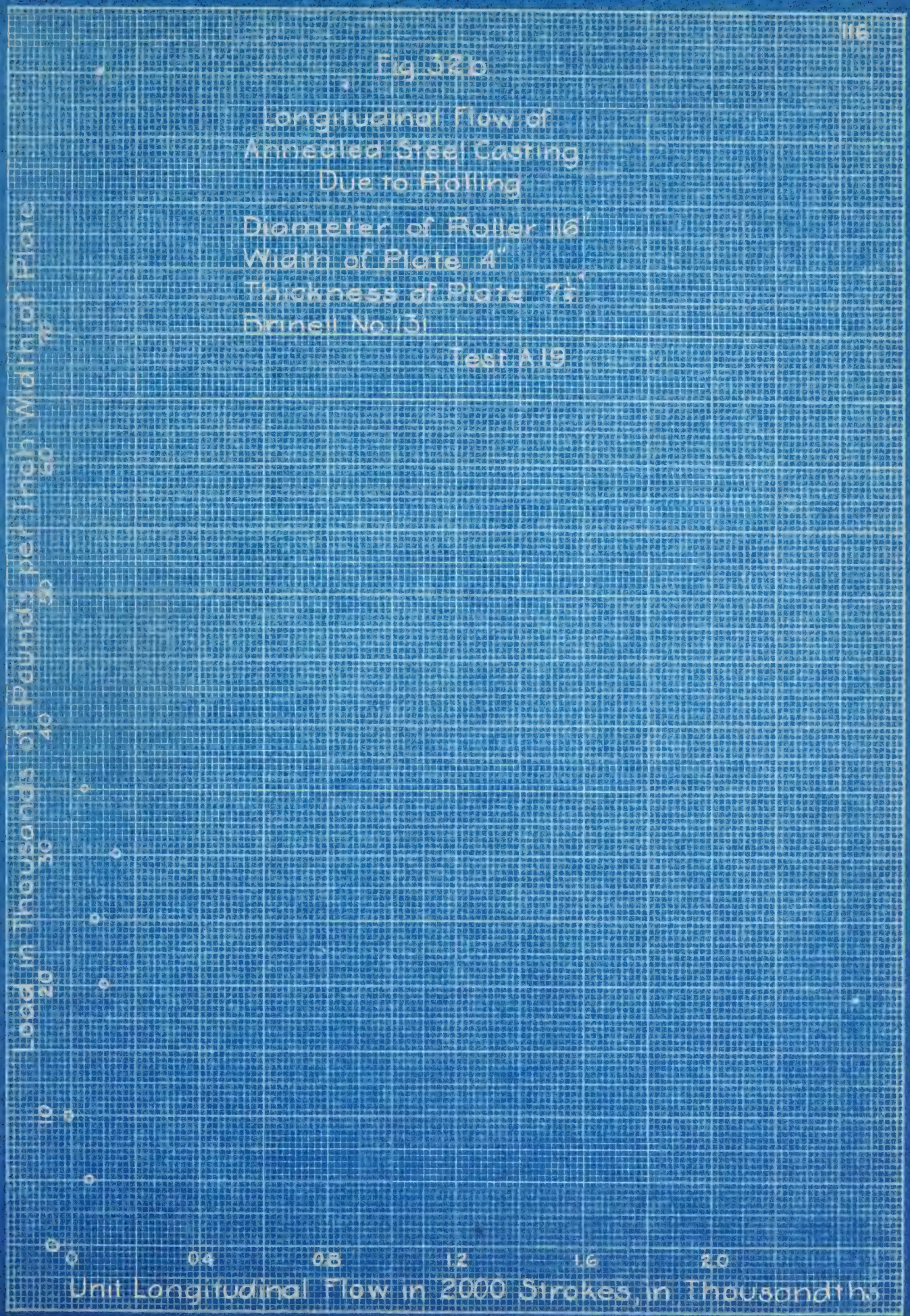


Fig. 33a

Lateral Flow of
Annealed Steel Casting
Due to Rolling

Diameter of Roller 116"
Width of Plate 4'
Thickness of Plate 4¾"
Brinell No. 153

Test A20

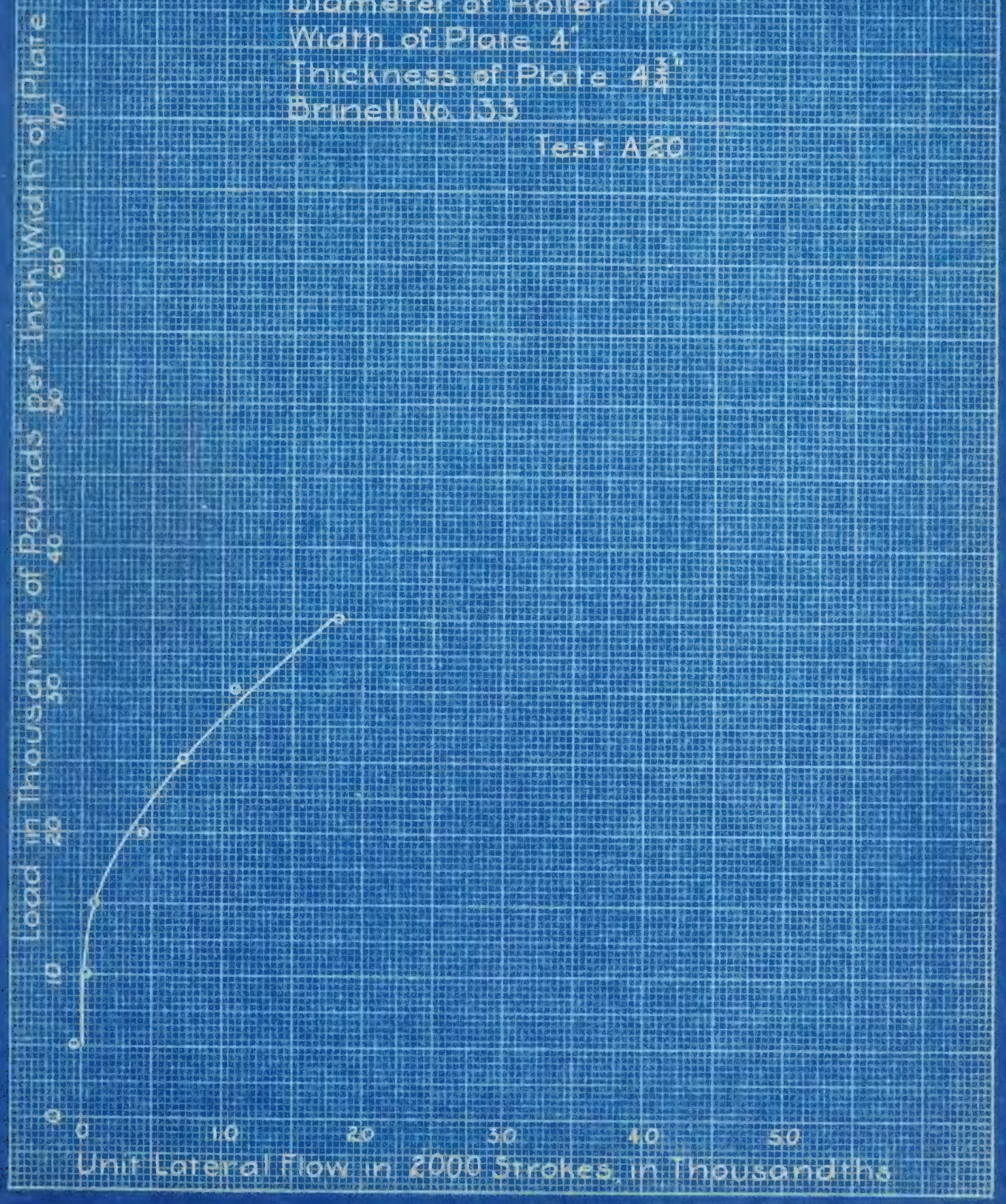


Table 6
Longitudinal Flow of
Annealed Steel Casting
Due to Rolling
Diameter of Roller 16"
Width of Plate 4"
Thickness of Plate 4"
Brinell No. 150
Test A 20
Unit Longitudinal Flow in 2000 Strokes in Thousandths
0
0.4
0.8
1.2
1.6
2.0
10
20
30
40
50
60
70

Fig 34b

Longitudinal Flow in
Annealed Steel Casting
Due to Rolling

Diameter of Roller 18"
Width of Plate 4"
Thickness of Plate 3/4"
Brinell No. 135
Test A21

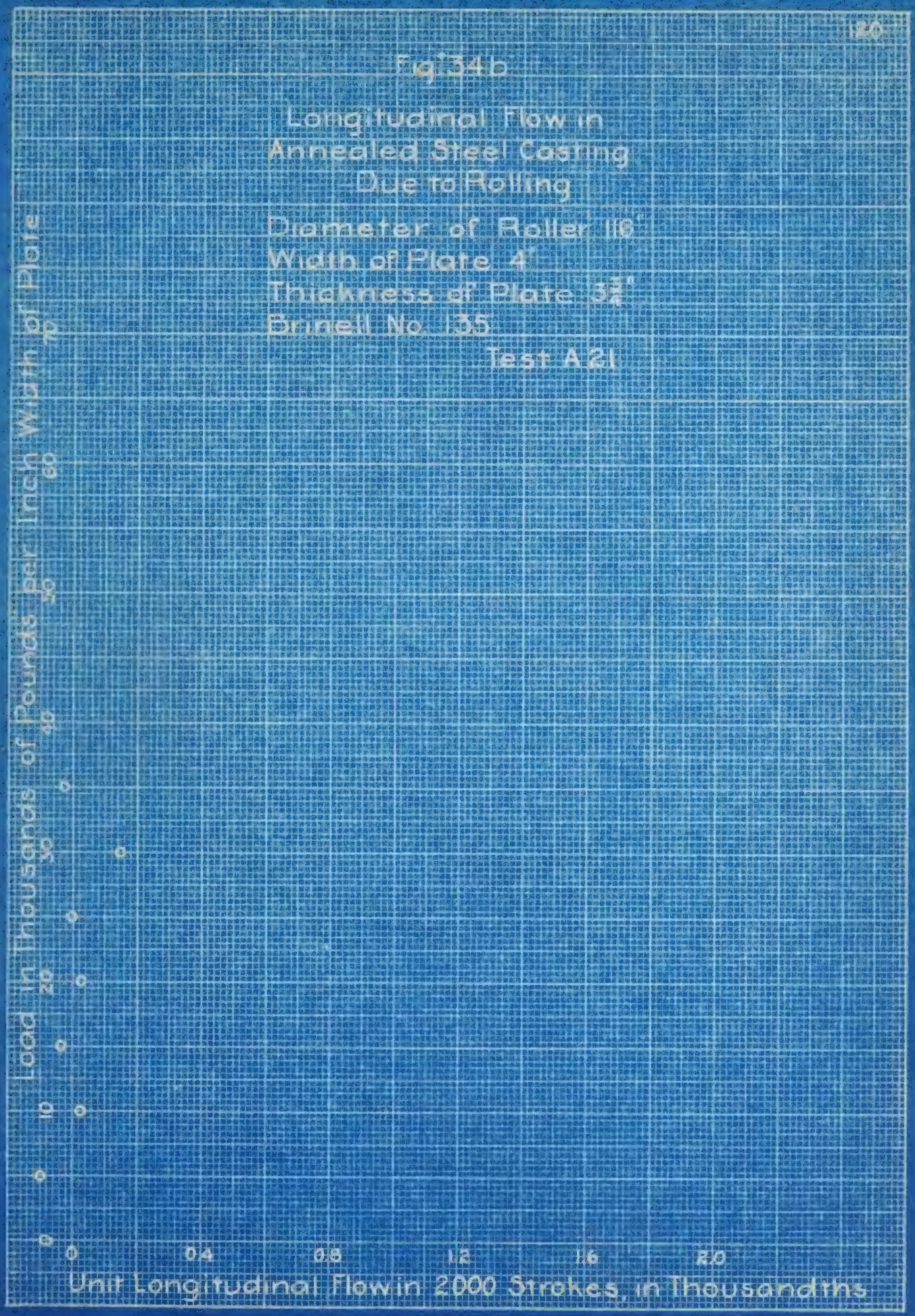


Fig 35a

Lateral Flow of
Annealed Steel Casting
Due to Rolling

Diameter of Roller 16"
Width of Plate 4"
Thickness of Plate 2¾"
Brinell No. 131
Test A22

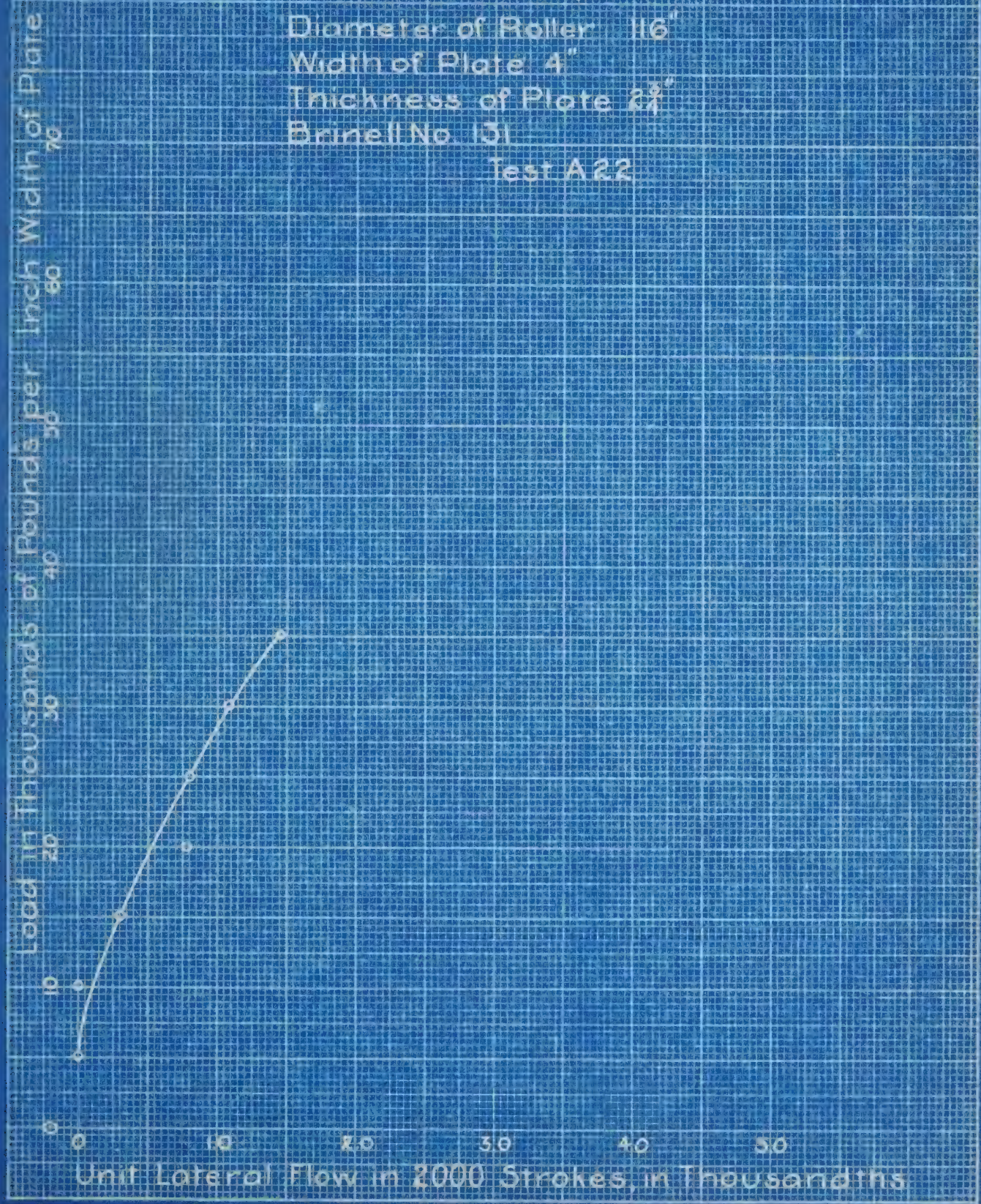
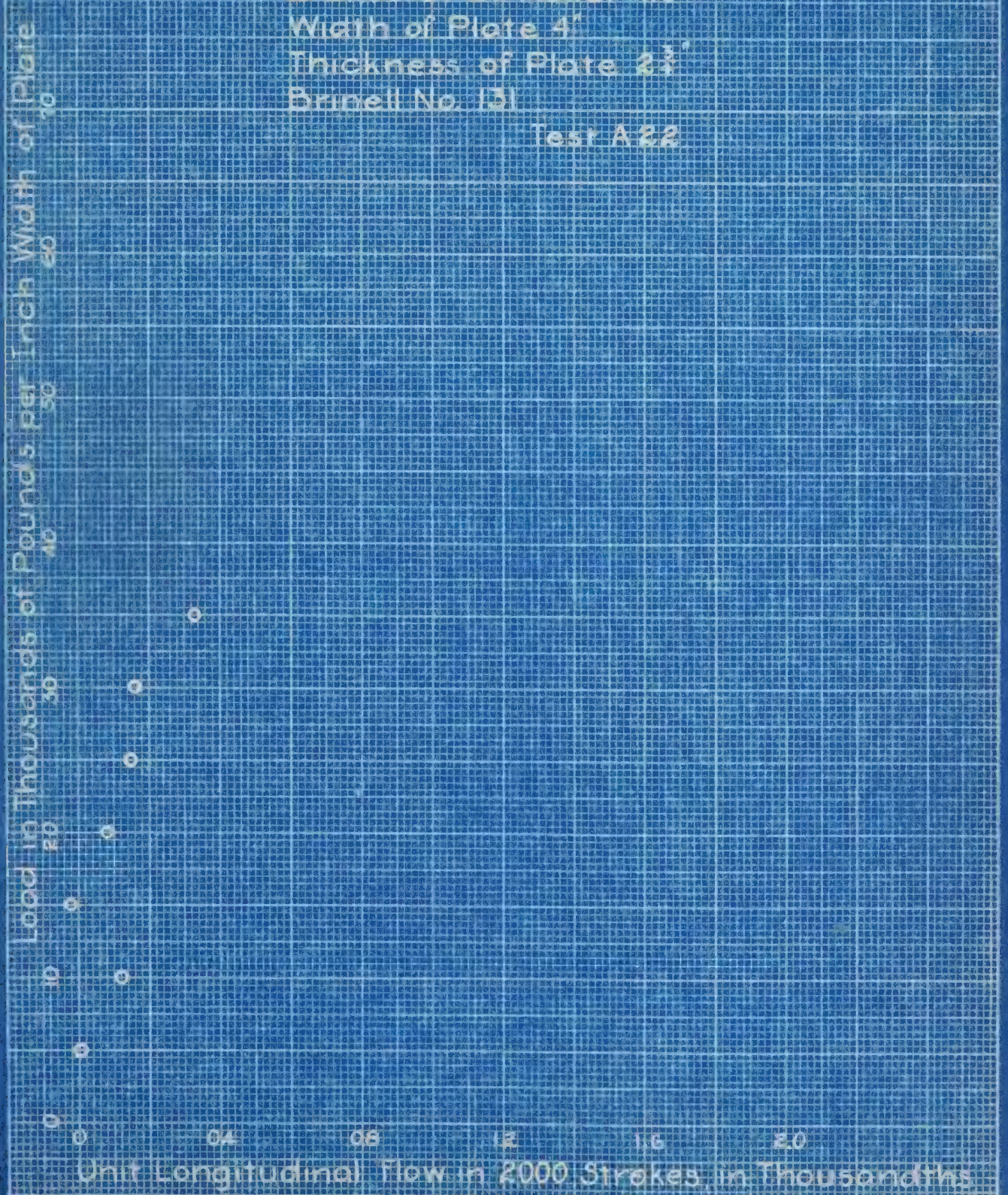


Fig 35b

Longitudinal Flow of
Annealed Steel Casting
Due to Rolling

Diameter of Roller 116"
Width of Plate 4'
Thickness of Plate 2 3/4"
Brinell No. 131
Test A 22



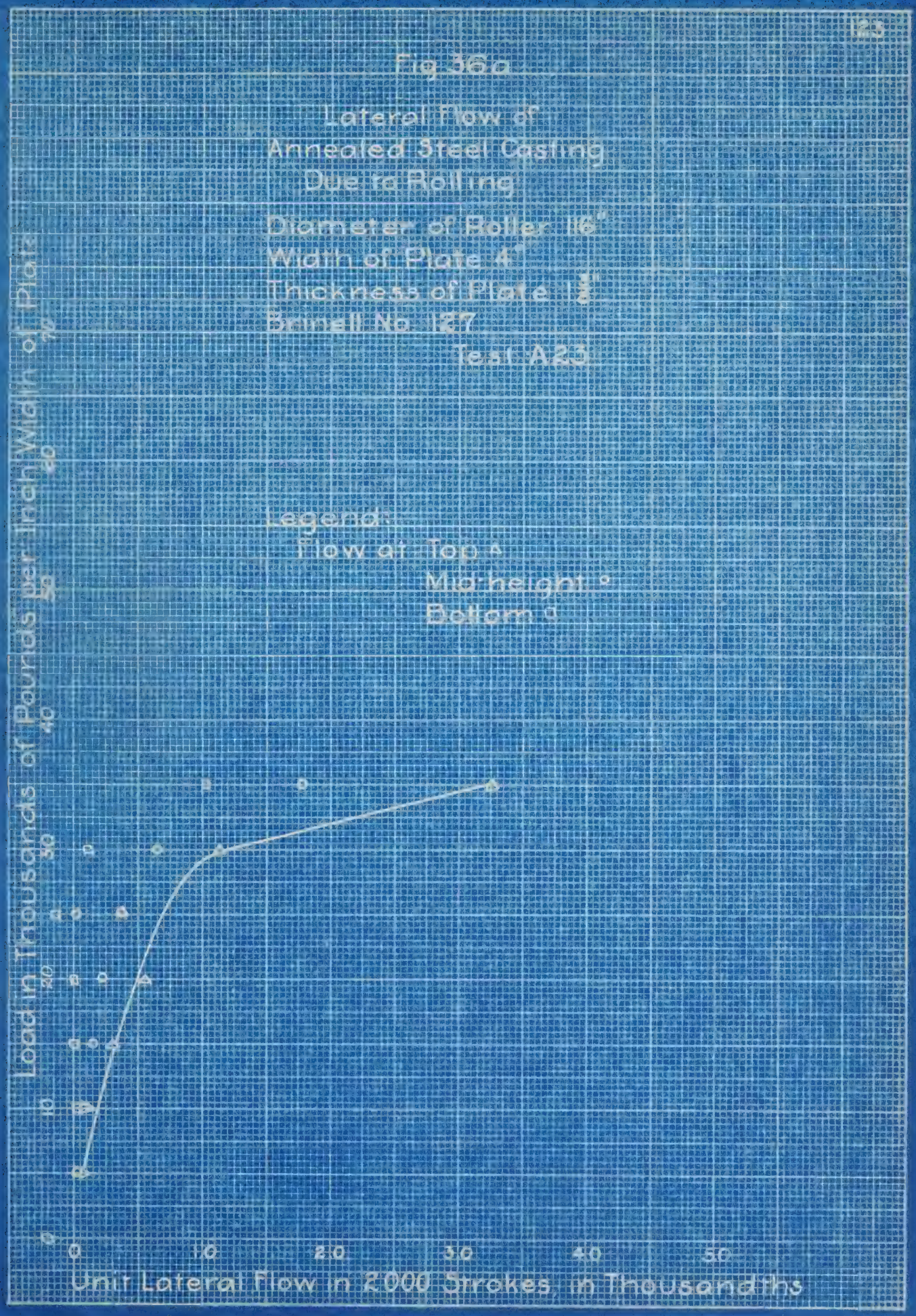


Fig. 36a
Lateral Flow of
Annealed Steel Casting
Due to Rolling
Diameter of Roller 16"
Width of Plate 4"
Thickness of Plate 1"
Brinell No. 127
Test A23
Legend:
Flow at Top
Mid-height
Bottom
Load in Thousands of Pounds per Inch Width of Plate
0
10
20
30
40
50
Unit Lateral Flow in 2000 Strokes, in Thousandths

Fig 36 b

Longitudinal Flow of
Annealed Steel Casting
Due to Rolling

Diameter of Roller 116"
Width of Plate 4"
Thickness of Plate 1⅜"
Brinell No. 127
Test A 23

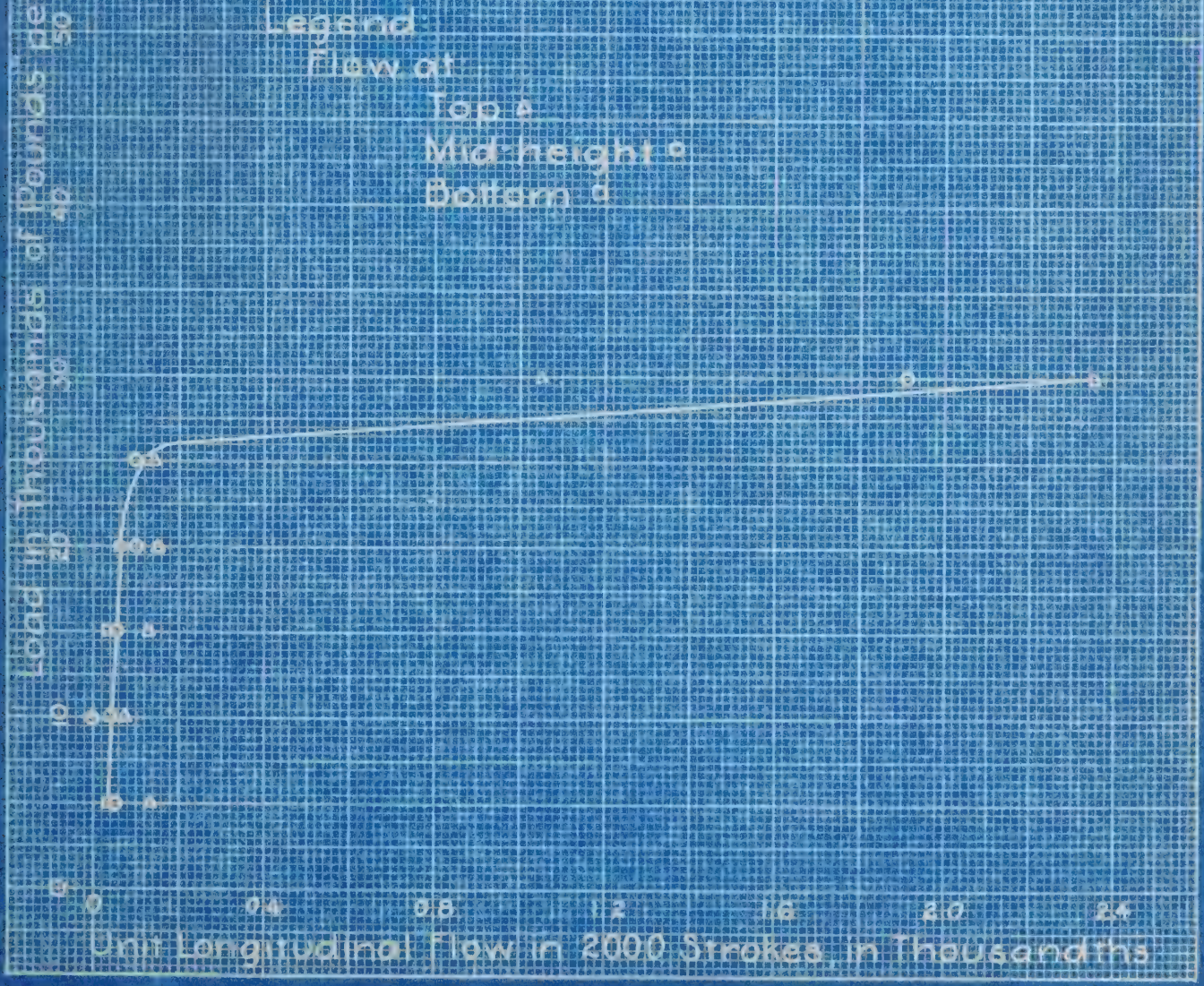


Table 5

Critical Loads

Rolling Tests of Thick Plates
Diameter of Roller 116"

Test	Thickness of Plate	Critical Load
A17	$8\frac{1}{2}$"	32 000
A18	$7\frac{1}{4}$"	30 000
A19	6"	30 000
A20	$4\frac{3}{4}$"	28 000
A21	$3\frac{3}{4}$"	27 000
A22	$2\frac{3}{4}$"	29 000
A23	$1\frac{3}{8}$"	28 500

The yield point of the material was increased by the cold working effect in every case whereas the ultimate strength was decreased except in A12 where it increased very slightly. The reduction of area and percent elongation was less in the tensile specimens taken from the rolled portion than those from the unrolled portion.

The values of the critical load determined by lateral flow are given in Table V. It appears that the thickness of plate when greater than (1 + .004D) inches has little or no effect on the critical load.

PART II.

II. ELASTIC FLOW.

II. ELASTIC FLOW.

1. Forward. The time consumed in the rolling process of a single test averaged about 12 hours. A method of determining the critical load from elastic flow would be of great advantage because the number of strokes at each load could be reduced from 1000 or 2000 to a very few in the short period required to observe the elastic flow and a large part of the cold working effect would also be eliminated. These tests were made to study the elastic flow of plate and develop a method of determining the critical load from the elastic flow.

Measurements for permanent and elastic lateral and longitudinal flow were made on the plates tested in the study of the effect of thickness of plate on the critical load.

2. Description of Test. This study was made at the same time as the study of the thickness of plate. The specimen, apparatus, and procedure of test are described under that study.

In addition , measurements were made for elastic lateral and longitudinal flow of plate. The measurement of elastic lateral flow is described on page 23. The elastic longitudinal flow was measured by holding the strain gage in the gage holes while the roller was in motion. The difference in the reading when the roller was at the end and middle of the stroke is interpreted to be the elastic longitudinal flow of the plate.

3. Results. The relation between load and the permanent flow

of plate is shown in Figures 30 to 36 inclusive. The relation between load and the elastic flow of plate is shown in Figures 37 to 44 inclusive.

The curves for elastic flow in thick plates indicate no "break" whereby a critical load can be determined. In the two thinnest plates the elastic flow increases, reaches a maximum, and decreases. The maximum elastic flow in the plate 1-3/8 inches thick occurs at a load of 30,000 pounds per inch width of plate while the critical load from permanent longitudinal flow is 25,000 pounds per inch of width and from permanent lateral flow it is 29,200 pounds per inch of width. The maximum elastic lateral flow in the plate $2\frac{3}{4}$ inches thick occurs at a load of 25,000 pounds per inch width of plate while the critical load from permanent lateral flow is 28,600 pounds per inch width of plate.

For the range of thicknesses studied the elastic flow gives no satisfactory criterion for determining the critical load. There is, however, an indication that for thinner plates, the elastic flow may indicate the critical load.

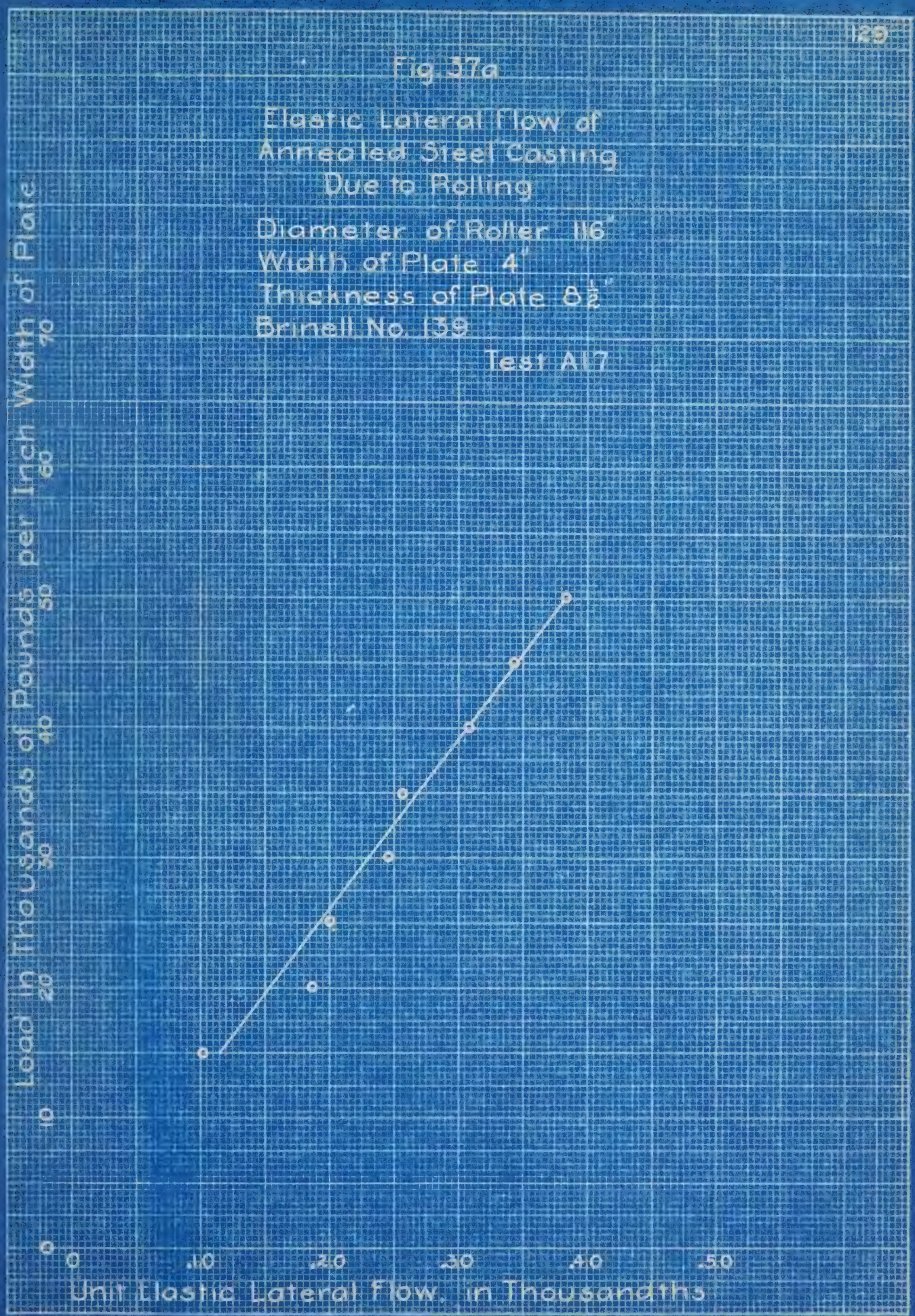


Fig 37a
Elastic Lateral Flow of
Annealed Steel Casting
Due to Rolling
Diameter of Roller 116"
Width of Plate 4"
Thickness of Plate 8½"
Brinell No. 139
Test A117
Load in Thousands of Pounds per Inch Width of Plate
0
10
20
30
40
50
60
70
0
.10
.20
.30
.40
.50
Unit Elastic Lateral Flow, in Thousandths

Fig 36a

Elastic Lateral Flow of Annealed Steel Casting Due to Rolling

Diameter of Roller 116"
Width of Plate 4'
Thickness of Plate 7/8"
Brinell No. 129
Test A1B

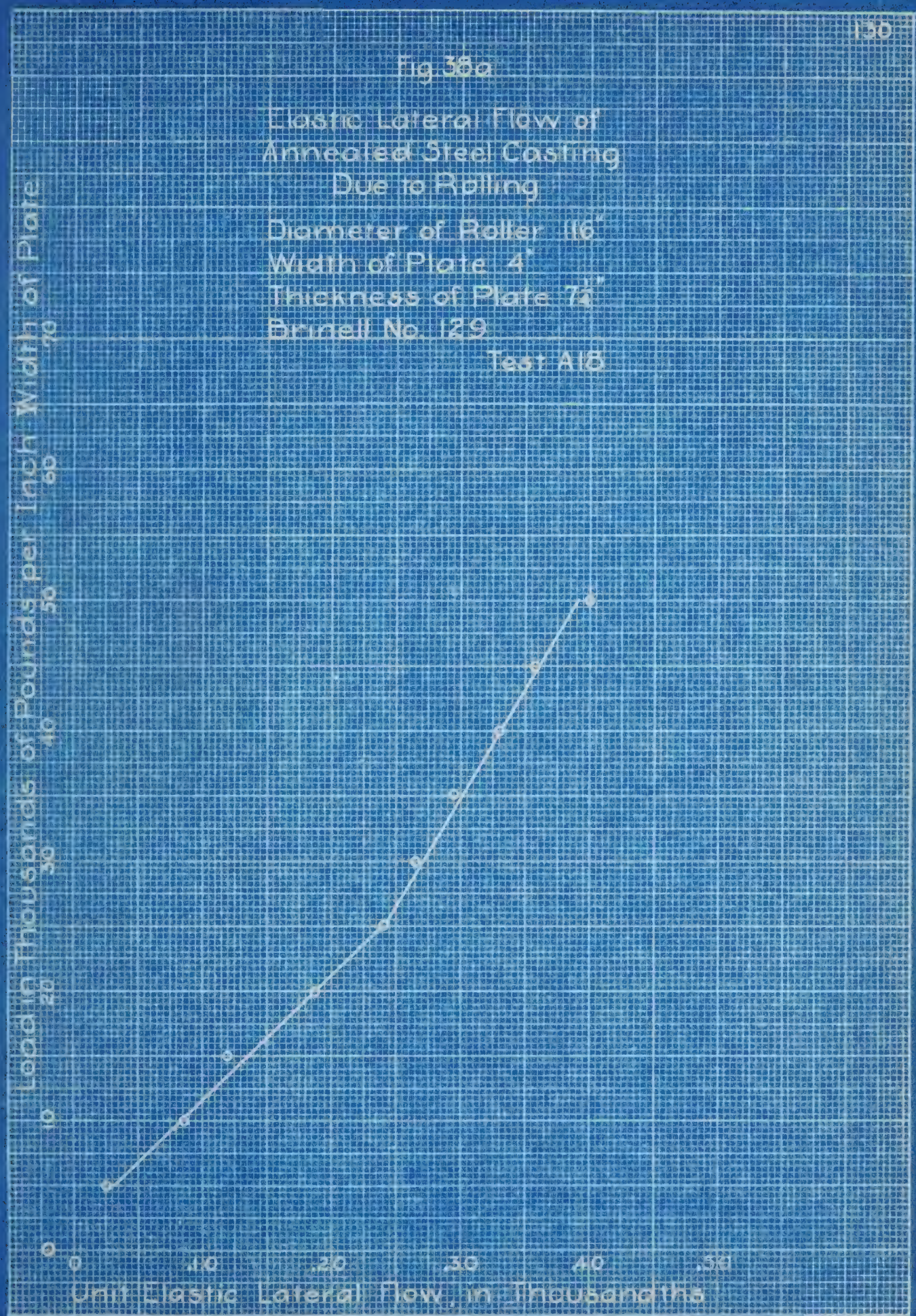


Fig 38b

Elastic Longitudinal Flow of
Annealed Steel Casting
Due to Rolling

Diameter of Roller 11.6"
Width of Plate 4"
Thickness of Plate 7¼"
Test A18

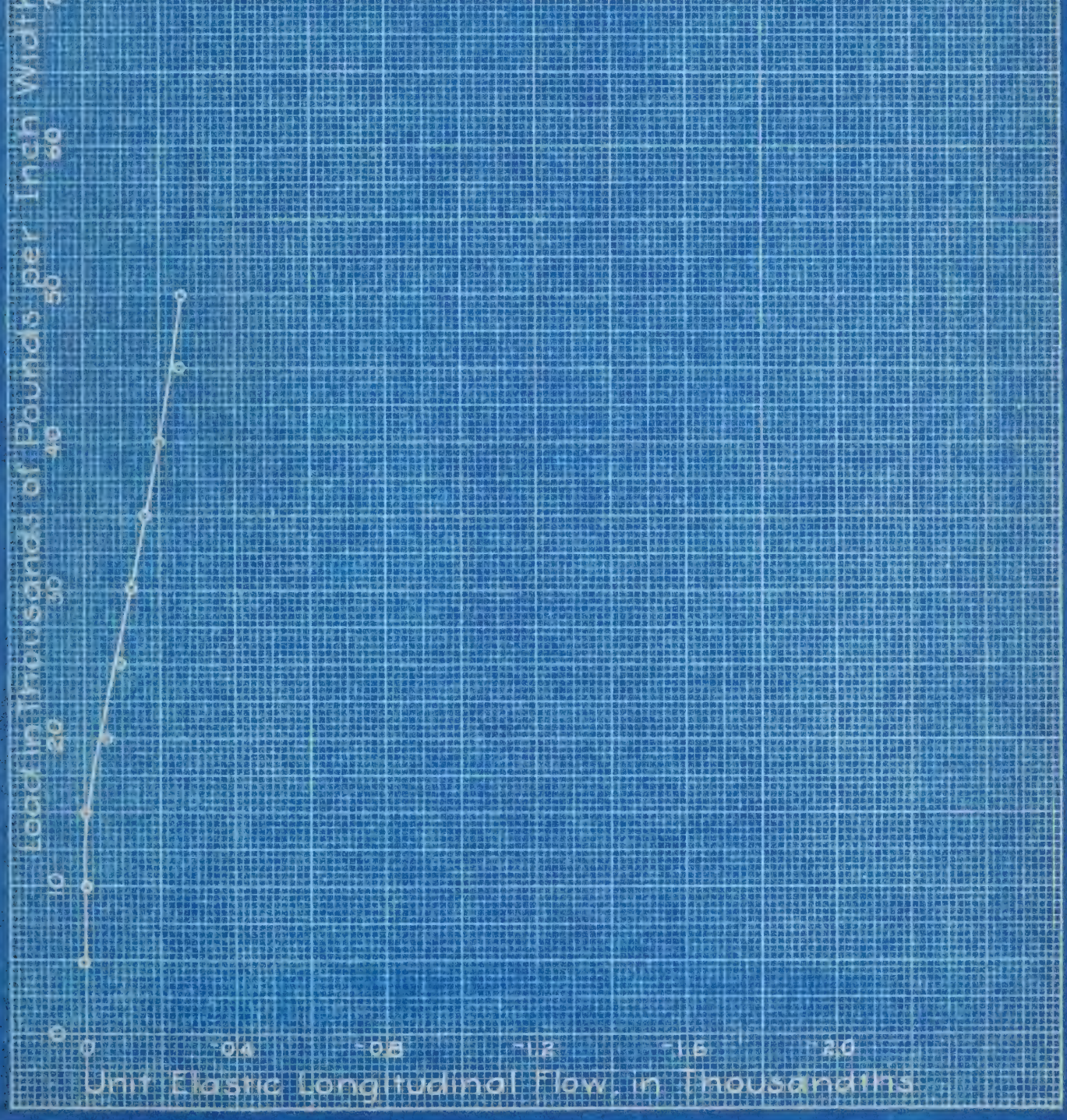


Fig 39a

Elastic Lateral Flow of
Annealed Steel Casting
Due to Rolling

Diameter of Roller 11.6"
Width of Plate 4"
Thickness of Plate 6"
Brinell No. 131
Test A19

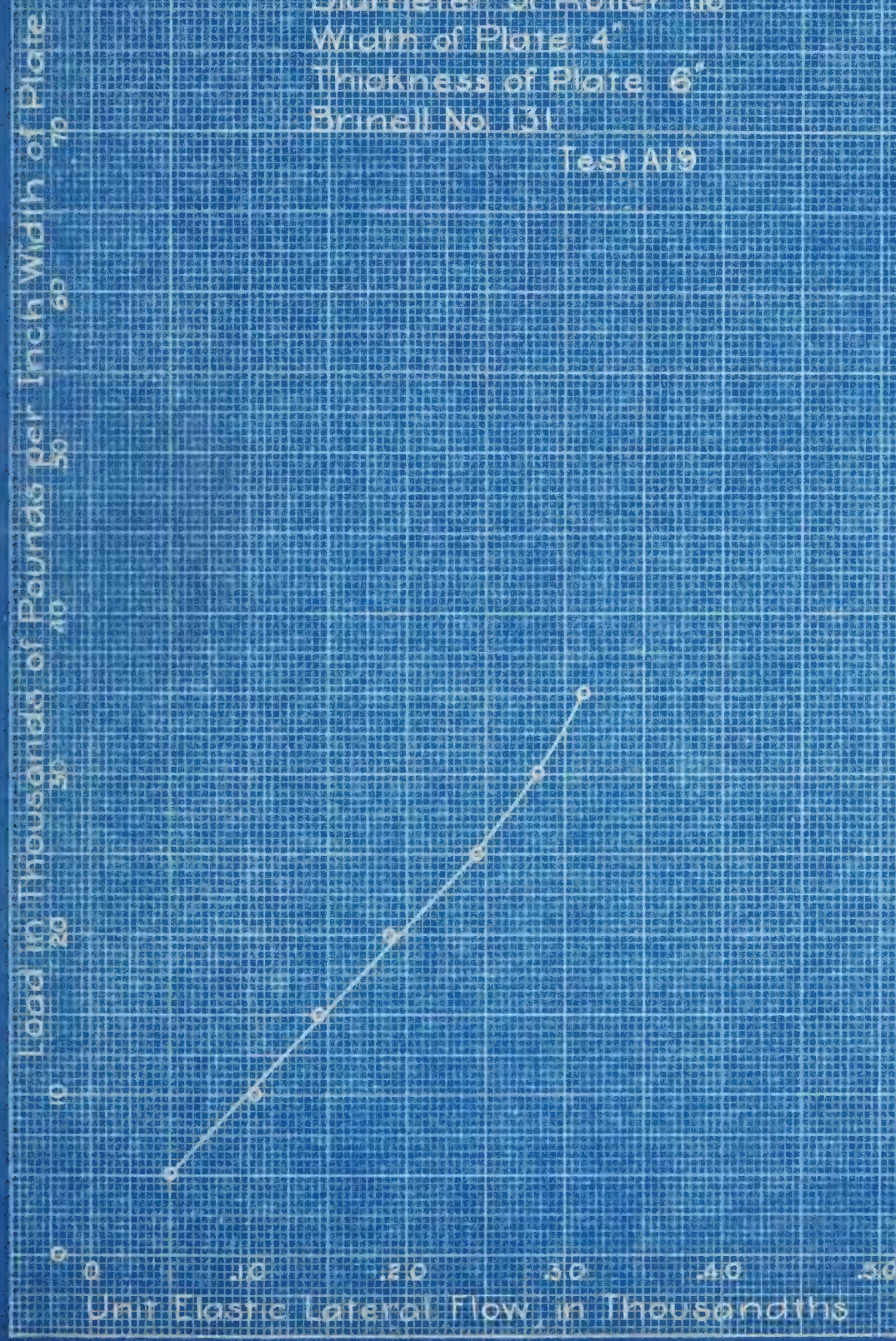


Fig 39b

Elastic Longitudinal Flow of
Annealed Steel Casting
Due to Rolling

Diameter of Roller 116"
Width of Plate 4"
Thickness of Plate 6"
Brinell No. 131

Test A19

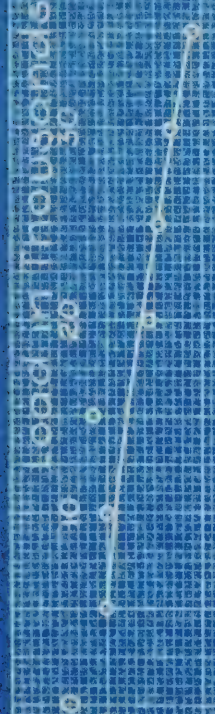
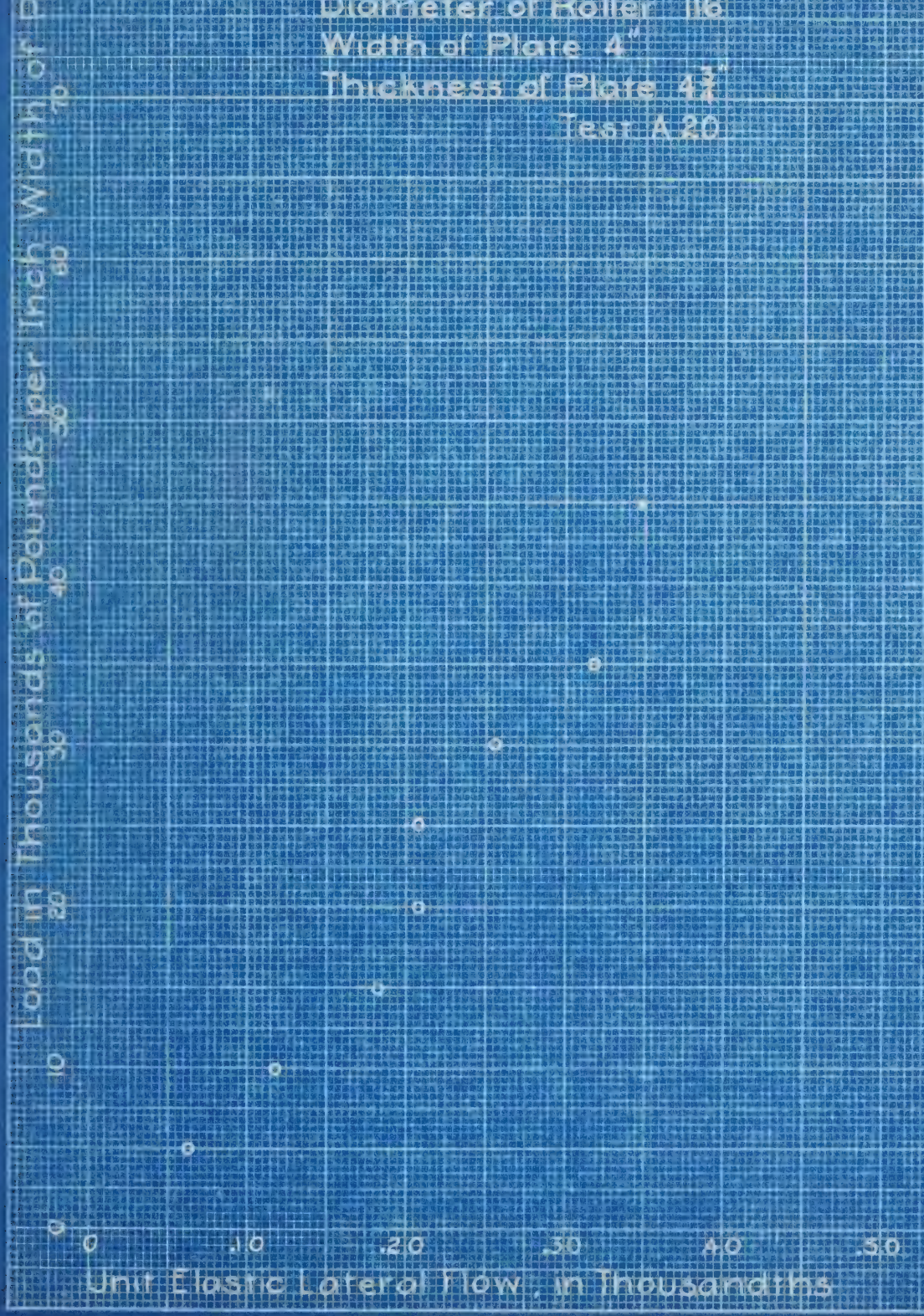


Fig 40a

Elastic Lateral Flow of
Annealed Steel Casting
Due to Rolling

Brinell No. 135
Diameter of Roller 16"
Width of Plate 4"
Thickness of Plate 4¾"
Test A 20



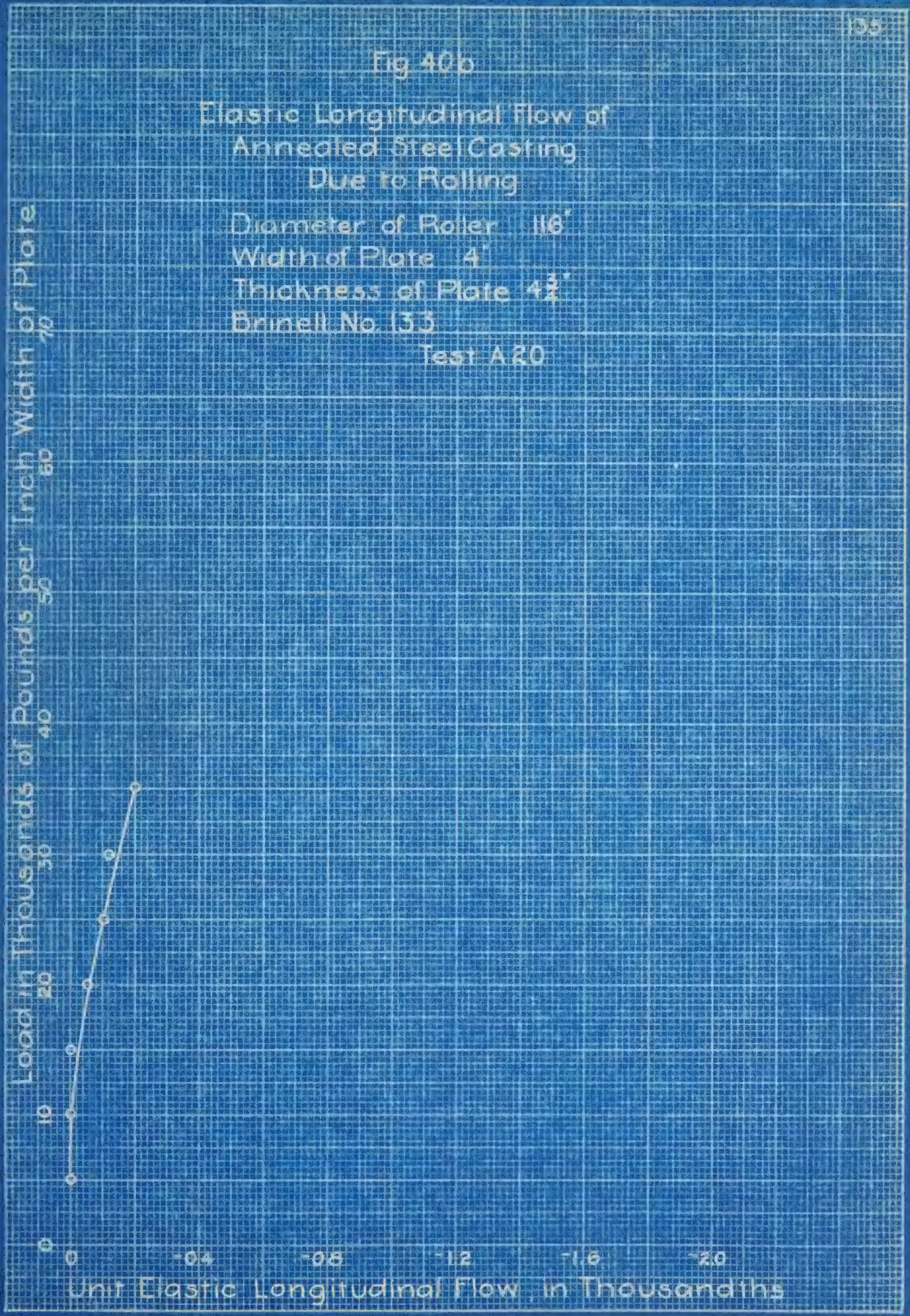


Fig 40b
Elastic Longitudinal Flow of
Annealed Steel Casting
Due to Rolling
Diameter of Roller 116"
Width of Plate 4"
Thickness of Plate 4¾"
Brinell No. 135
Test A20
Load in Thousands of Pounds per Inch Width of Plate
0
10
20
30
40
50
60
70
0
.04
.08
.12
.16
.20
Unit Elastic Longitudinal Flow in Thousandths

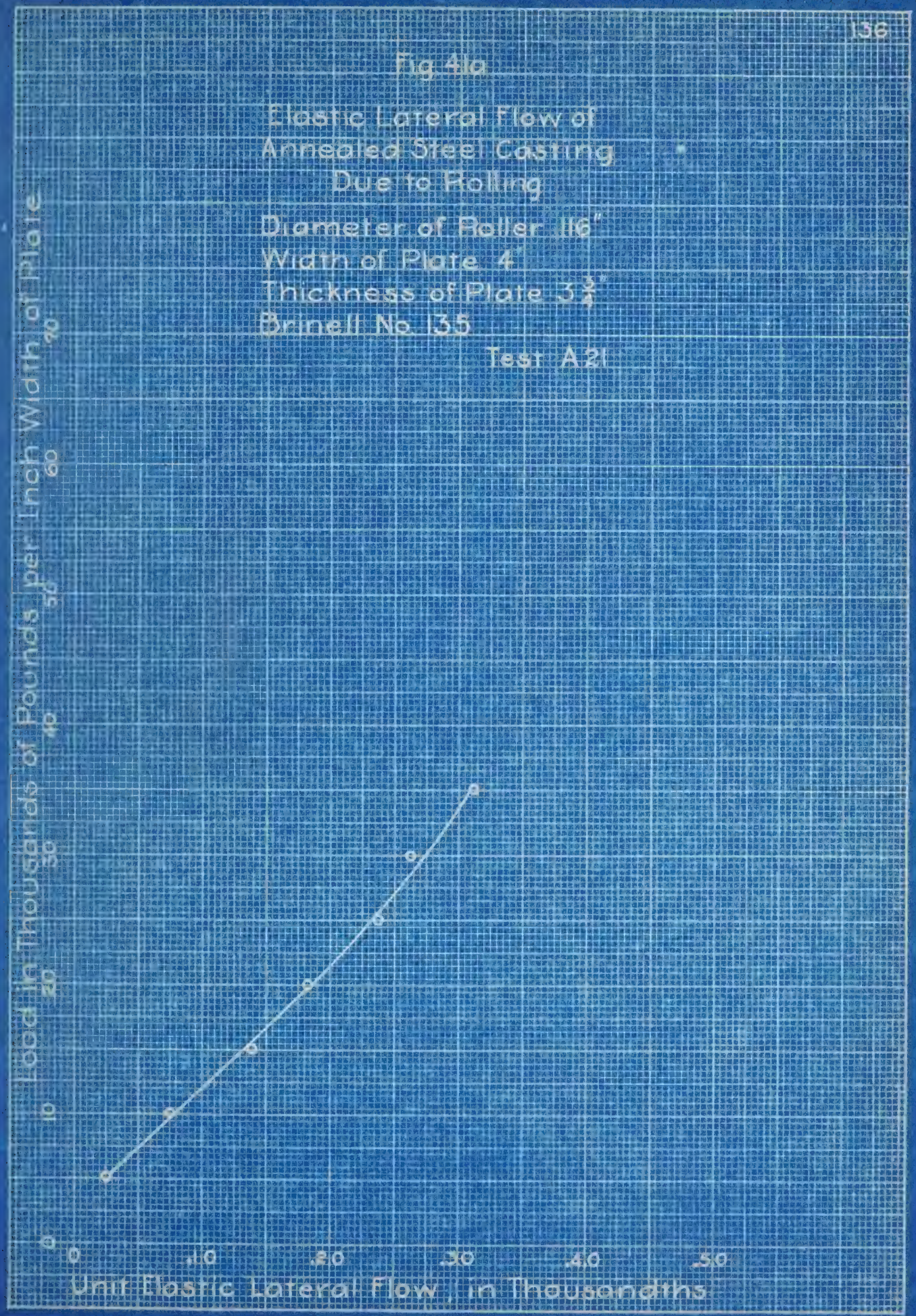


Fig 41a
Elastic Lateral Flow of
Annealed Steel Casting
Due to Rolling
Diameter of Roller 116"
Width of Plate 4"
Thickness of Plate 3 3/4"
Brinell No. 135
Test A21
Load in Thousands of Pounds per Inch Width of Plate
0
10
20
30
40
50
60
70
.10
.20
.30
.40
.50
Unit Elastic Lateral Flow in Thousandths

Fig 41 a

Elastic Longitudinal Flow of
Annealed Steel Casting
Due to Rolling

Diameter of Roller 116"
Width of Plate 4
Thickness of Plate 3¾"
Brinell No. 135

Test A&I

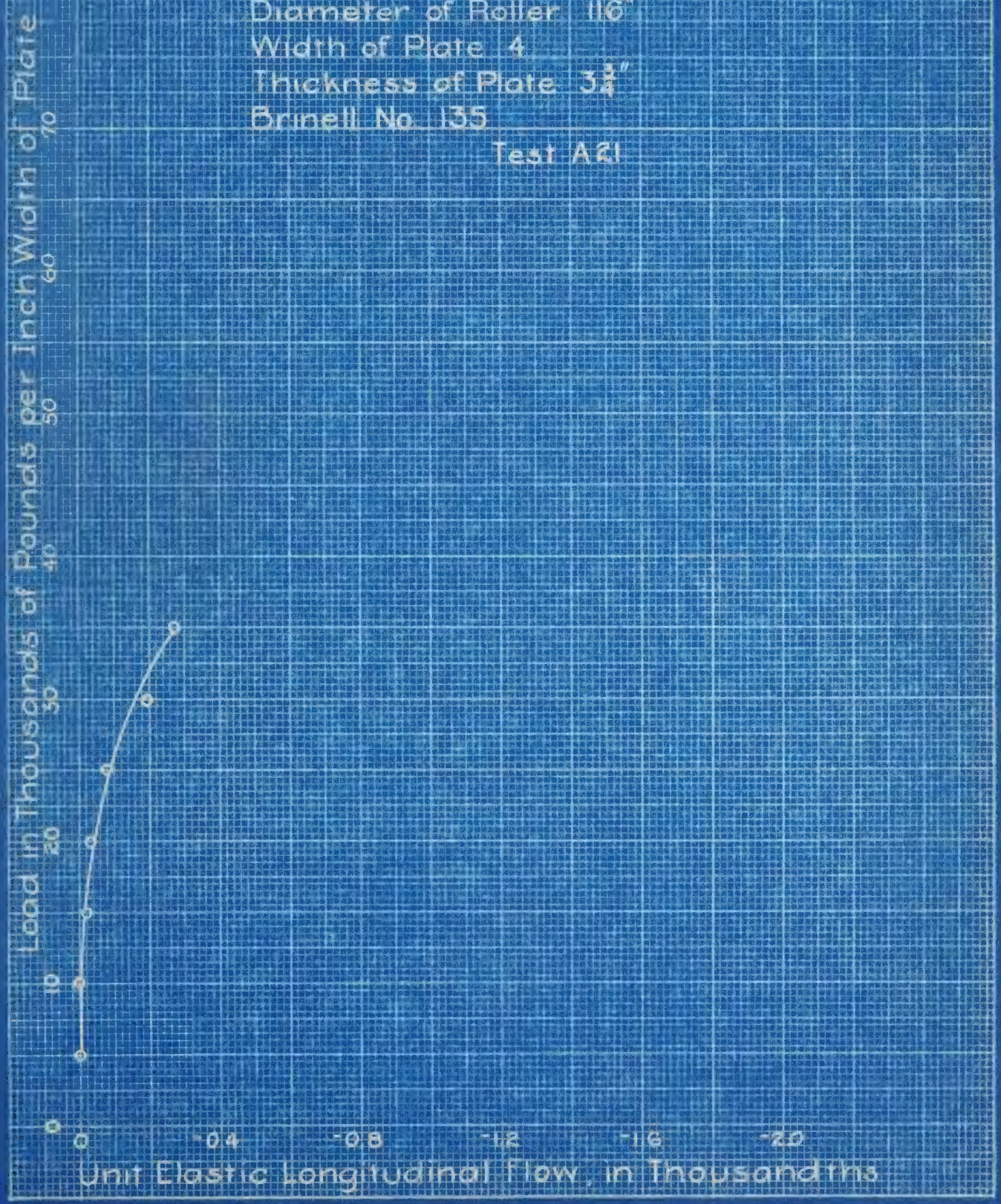


Fig 42a

Elastic Lateral Flow of
Annealed Steel Casting
Due to Rolling
Diameter of Roller 16"
Width of Plate 4"
Thickness of Plate 2¾"
Brinell No. 131
Test A22

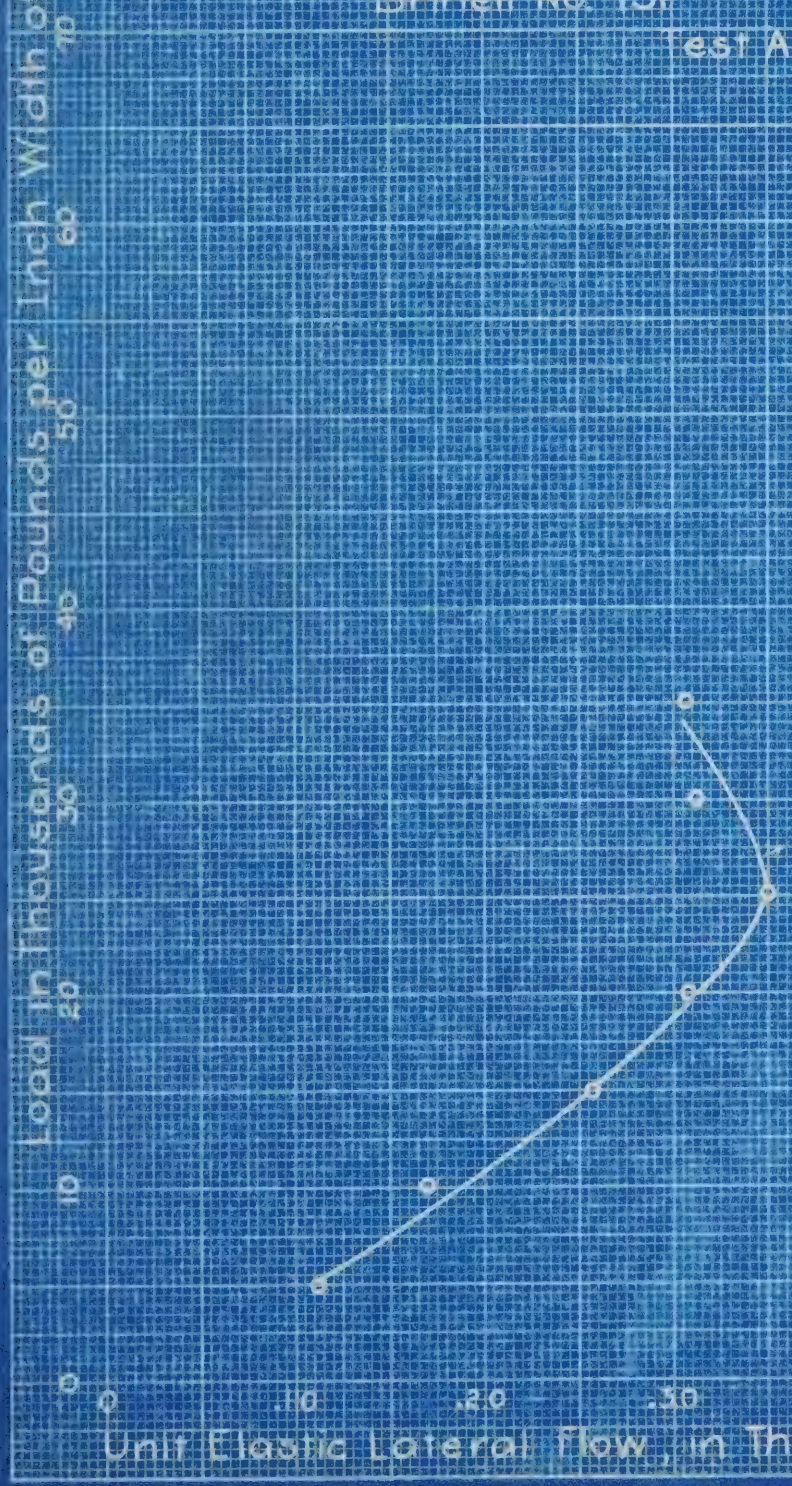


Fig. 42 b

Elastic Longitudinal Flow of
Annealed Steel Casting
Due to Rolling

Diameter of Roller 116"
Width of Plate 4"
Thickness of Plate $2\frac{3}{4}$"
Brinell No. 131

Test A22

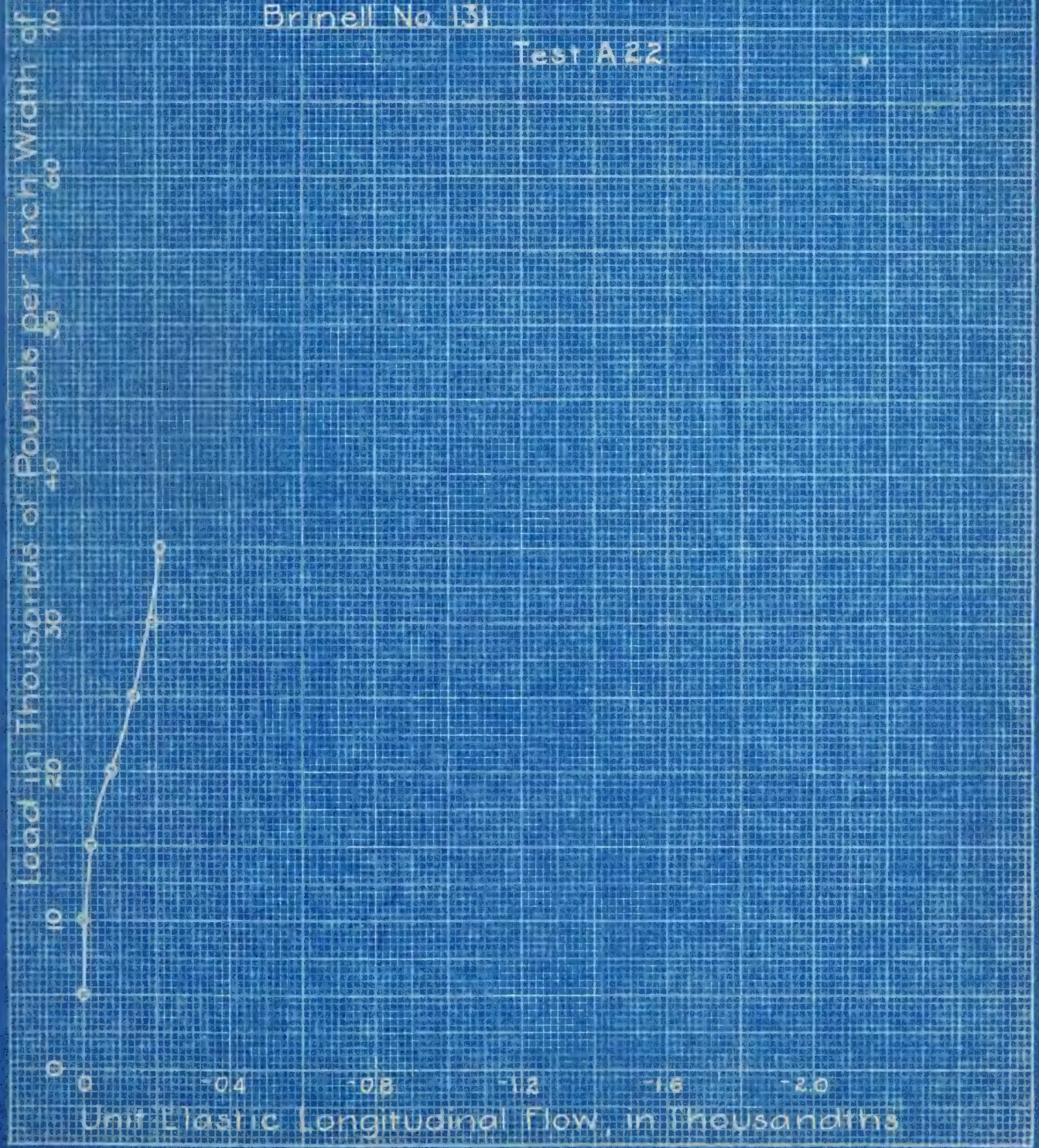


Fig. 43a

Elastic Lateral Flow of Annealed Steel Casting Due to Rolling

Diameter of Roller 16"
Width of Plate 4"
Thickness of Plate $1\frac{3}{8}$"
Brinell No. 127

Test A23

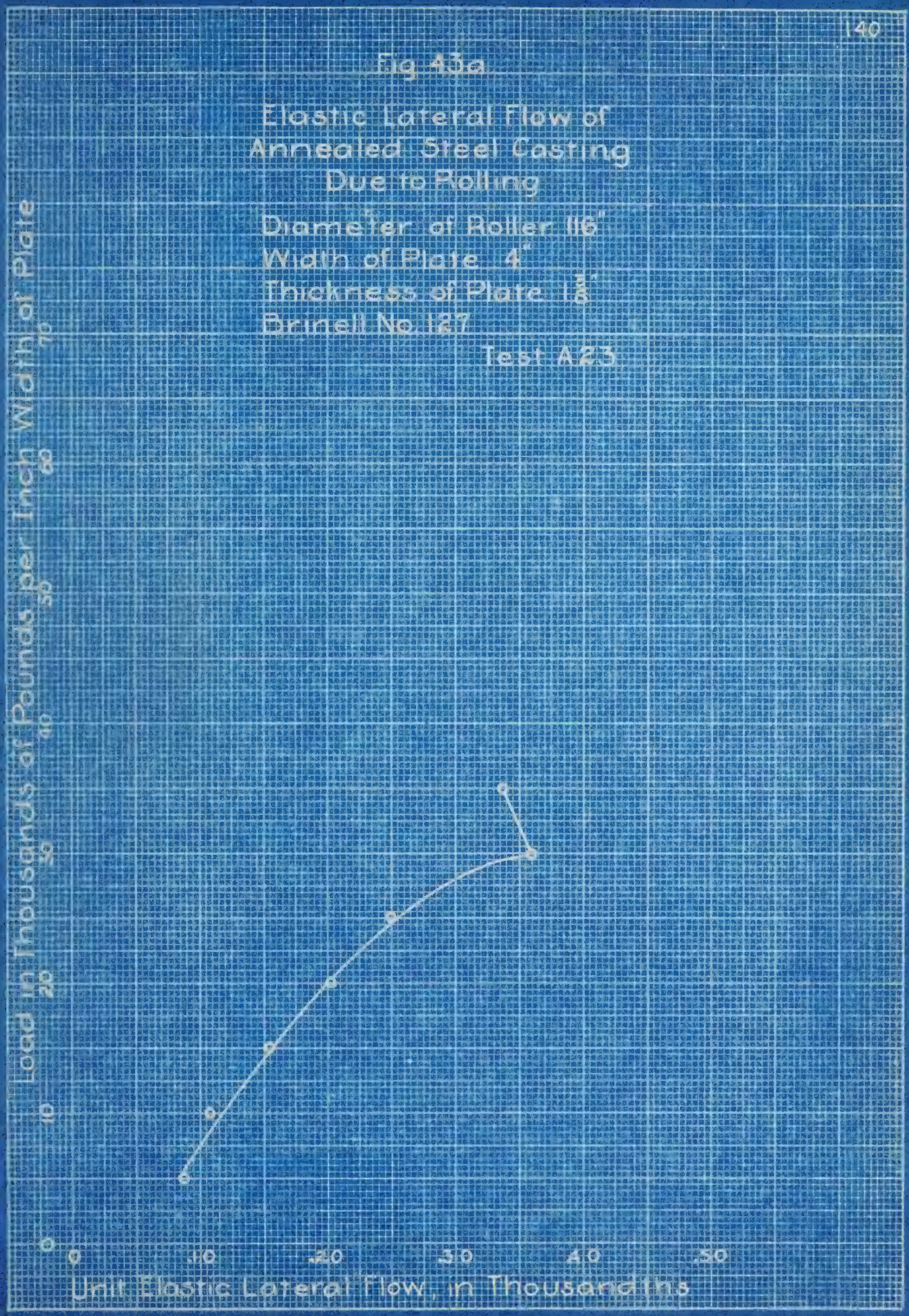


Fig 43b
Elastic Longitudinal Flow of
Annealed Steel Casting
Due to Rolling
Diameter of Roller 116"
Width of Plate 4"
Thickness of Plate 1 3/8"
Brinell No. 127
Test A23
Load in Thousands of Pounds per Inch Width of Plate
0
10
20
30
40
50
60
70
0
-0.4
-0.8
-1.2
-1.6
-2.0
Unit Elastic Longitudinal Flow in Thousandths

PART II.

III. THE CARRYING CAPACITY OF A STEEL CASTING HAVING AN H-SECTION.

III. THE CARRYING CAPACITY OF A STEEL CASTING HAVING AN H-SECTION.

1. Foreword. Usually sole plates have a rectangular cross-section. According to the equations of Hertz, the plane of maximum stress occurs a small distance from the bearing surface. The remainder of the material is understressed, part of which can be considered idle metal.

By using very thick sole plates the rolling load is distributed over a greater length of the supporting girders. The thickness of plate giving the maximum resistance to lateral flow as determined by Professor Wilson is 1 inch + 0.0040 which in the case of a 40 foot roller is 2.92 inches. A sole plate as thin as that would not distribute the load very well to the supporting girder and one thicker than that would waste material. It seems that, by using a casting with an H-section, part of the idle material of a thick plate could be removed. The casting could also be more easily attached to the supporting girders.

This study was undertaken to develop a method of determining the carrying capacity of a steel casting having an H-section.

2. Method of Analysis. A semi-rational analysis was undertaken. Such a method must necessarily be based on certain assumptions regarding the distribution of loads on the flange to the web and the distribution of stress in the web.

It was assumed that the center line of the area of contact in the direction of the axis of the roller remained a straight line. This necessitates that the flanges of the roller and sole plate be

identical. This assumption is justified by the argument that due to symmetry the flanges will deflect symmetrically about the plane tangent to the roller through the center line of the area in contact.

A load on the flange was assumed to be distributed over a length of web, l, equal to the width of the area in contact, a, plus the distance from the load point to the edge of the web, d, plus the thickness of the flange, t, all divided by the square of the thickness of the flange, or $l = \frac{a + t + d}{t^2}$. The stress over this length was assumed uniform. Or the assumption may be stated that the maximum stress in the web is equal to the average stress over the assumed length of web.

The influence line for stress calculated on this assumption is shown in Figure 44.

By the use of Hertz' formula

$$a = 0.004\sqrt{PD},$$

the width of area in contact, a, can be calculated where P is the load per inch width of plate and D is the diameter of the roller in inches.

The displacement of the center line of the contact area relative to the base of the plate, neglecting the deformation in the web of the casting, is made up of two parts. They are:

(a) A deformation in the material due to the contact of the roller and plane surface. Prescott gives the equation for the depth of this impression as

$$w = -\frac{(1 - m)P_o}{2n} \cdot b$$

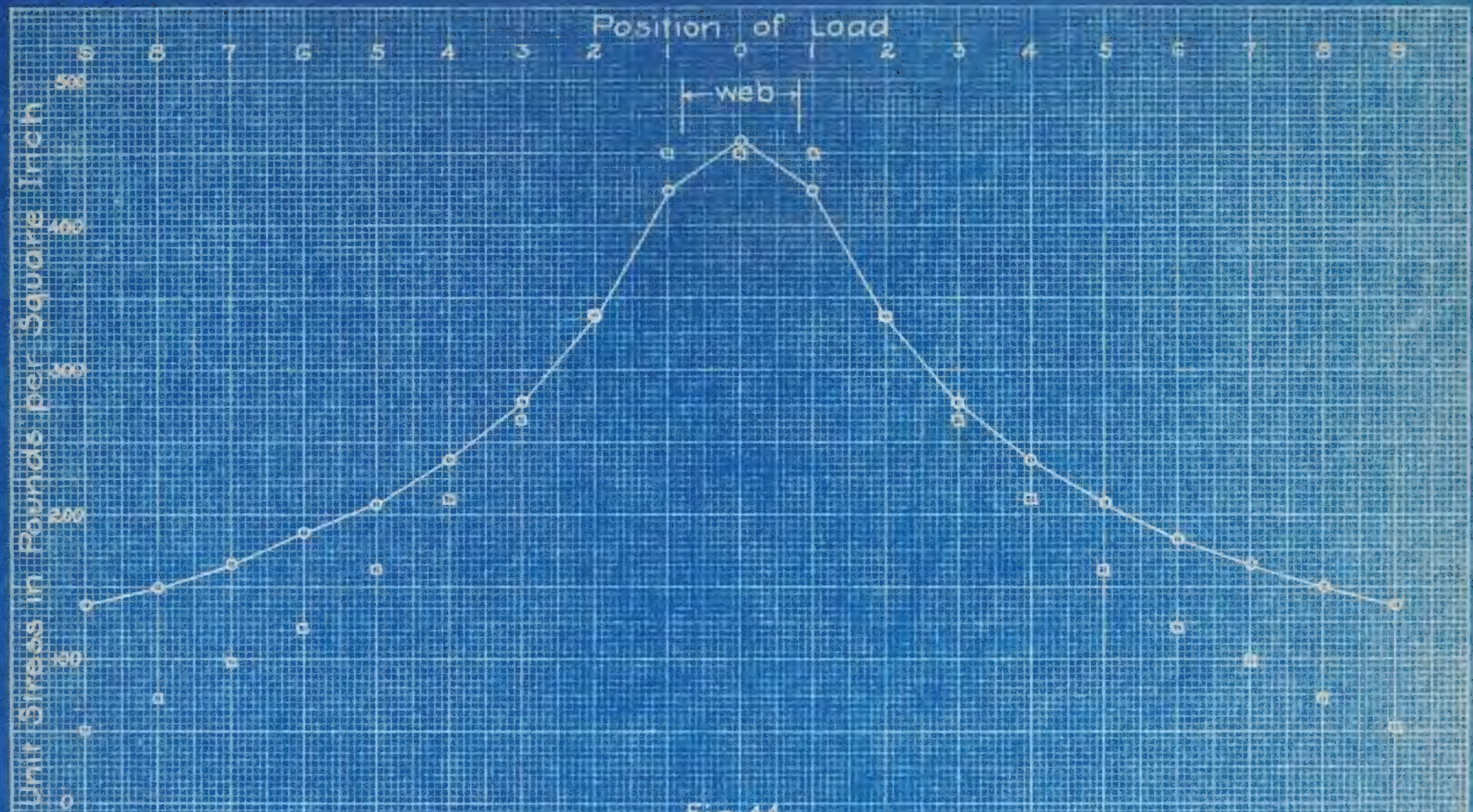


Fig. 44

Influence Line for Stress Due to a Total Load of 1000 Pounds
Calculated ○
Experimental □

where w = the depth of the impression

m = Poisson's ratio

P_o = the maximum unit pressure between cylinder and plate

n = modulus of elasticity in shear.

b = one half the width of area in contact.

(b) Deflection of the flange. The author made an extensive search for an equation giving this quantity but found none. The magnitude of this quantity is very small. An assumption of its magnitude unless very exact may give results very much in error. It seems that the deflection might vary inversely as a power of the thickness of the flange.

Tests were made on a medium grade steel casting having an H-section and the following dimensions to determine the deflection of the loaded flange,

length 10 inches

height ,back to back of flanges, 10 inches

flange width 10 inches

flange thickness 0.83

web thickness 0.81

The surfaces were machined and the fillet between flange and web removed.

Equal loads were placed on the flange symmetrically about the web. The bearing blocks on the flange were ½" x 1", the long side being parallel to the web. The deflection was measured at 4 pairs of points with dials mounted so the plunger bore on the under surface of the flange. The deflection ½ inch from the web was measured with a dial of the Last Word type in which one division

on the dial represents .0001 inch movement of the plunger. The deflection at other points was measured with Ames dials in which one division of the dial represents 0.001 inch movement of the plunger. In both cases, parts of a division were estimated. The load points were $\frac{1}{2}$ inch apart on the transverse center line of the flange. They were numbered from 0 to 9, 0 being over the web and 9 being near the edge of the flange. The set up is shown by the photographs in Figure 45. Influence lines for deflection were gotten by measuring the deflection at various points with the load at the load points. These lines are given in Figure 46.

The problem is to determine the distribution of load across the flange so that the impression of the roller plus the deflection of the flange is constant and still keep the unit stress within the allowable. Let the conditions of the problem be:

flange width $4\frac{1}{2}$ inches

flange thickness 0.83

web thickness 0.81

diameter of roller 18'9"

Poisson's ratio 0.30

modulus of elasticity in shear 12,000,000 pounds per square inch

elastic limit strength of material in tension = 32000 pounds per square inch.

Assume a distribution of load and calculate the depth of impression over the web and at the points where deflection was measured. If the impression plus the deflection is constant, the distribution is correct. The next thing to do is calculate the

Fig. 45

Set-up for Measuring the Deflection of the Flange of a Steel Casting having an H-Section

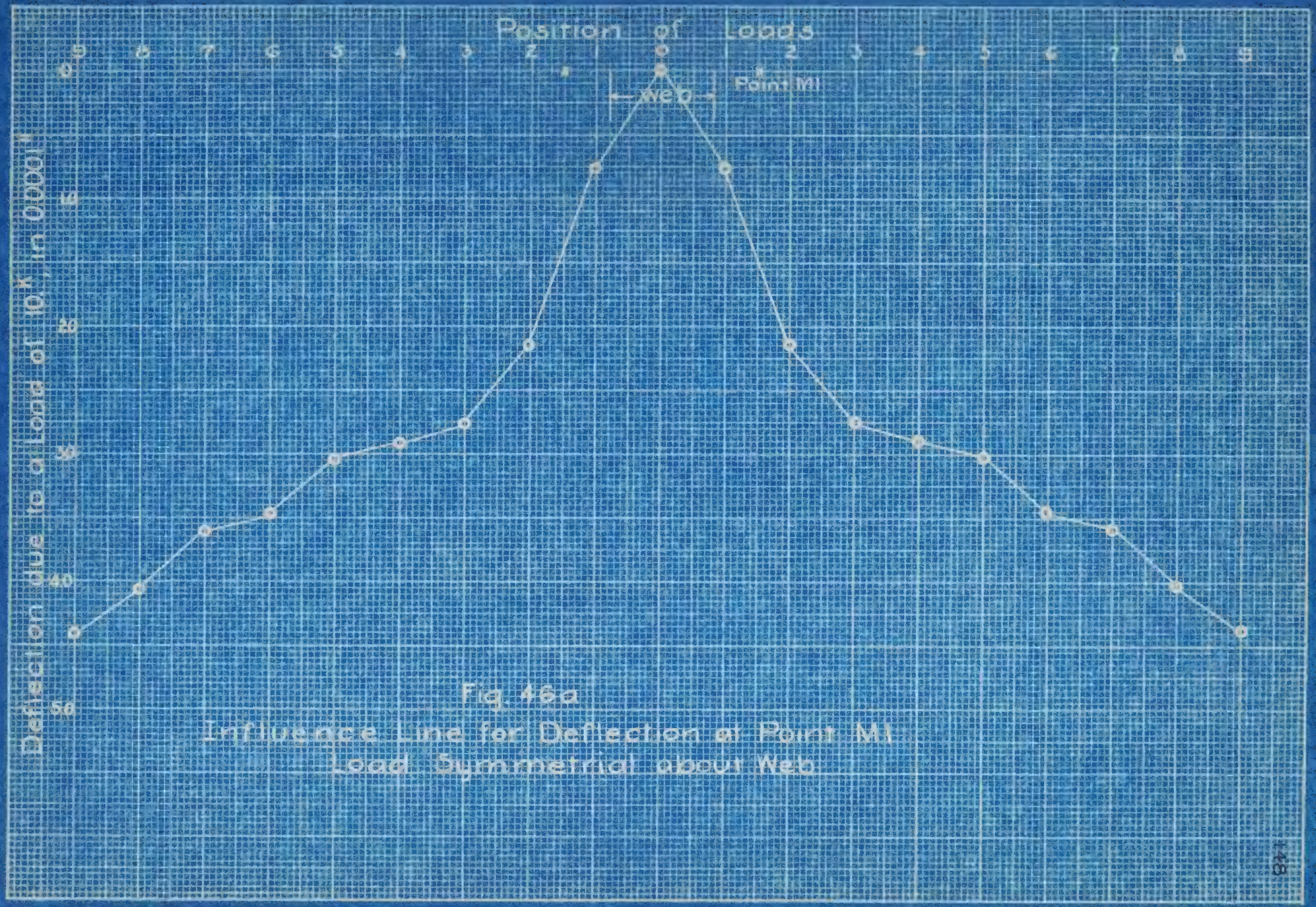


Fig. 46a
Influence Line for Deflection at Point M1
Load Symmetrical about Web

Fig. 46b
Influence Line for Deflection

stress. If the stress is near the allowable, the assumed loading is the capacity of the casting.

The procedure of calculation is as follows:

Assume a distribution of load across the flange,

9 at $\frac{1}{2}$" = $4\frac{1}{2}$"
load points

4	3	2	1	0	1	2	3	4
			load in thousands of pounds					
5.8	10.3	12.7	14.0	14.4	14.0	12.7	10.3	5.8 = 100

$$a_0 = 0.0004\sqrt{PD} = 0.006\sqrt{14,400} = 0.720$$

$$p_0 = \frac{2 \times 14,400}{\pi \times .36} = 25,500$$

$$w_0 = \frac{.7 \times 25,500}{2 \times 12 \times 10^6} \times .36 = .000268$$

$$a_4 = 0.006\sqrt{5,800} = 0.457$$

$$p_4 = \frac{2 \times 5800}{\pi \times 0.228} = 16,200$$

$$w_4 = \frac{.7 \times 16,200}{2 \times 12 \times 16^6} \times .228 = .000108$$

Δ due to load at 4 = .001160
" " " " " 3 = .001854
" " " " " 2 = .001164
" " " " " 1 = .000420
" " " " " 0 = 0

.004598 + .000108 = .004706

Stress in web due to load at 0 = 6,580
" " " " 1 = 11,860
" " " " 2 = 8,550
" " " " 3 = 5,720
" " " " 4 = 2,760
35,470 lb. per sq. in.

The material is overstressed. The influence line for stress says to place heavier loads farther from the web and the influence line for deflection says to put heavier loads over the web. Both conditions cannot be satisfied at once. Therefore the specimen will not carry 100,000 pounds.

Reduce the load.

9 at $\frac{1}{2}$" = $4\frac{1}{2}$"

4	3	2	1	0	1	2	3	4
4.0	7.2	9.0	9.8	10	9.5	9.0	7.0	4.0

$$a_0 = 0.006 \sqrt{10,000} = 0.6$$

$$p_0 = \frac{2 \times 10}{\pi \times 0.3} = 21,200$$

$$w_0 = \frac{.7 \times 21,200}{2 \times 12 \times 10^6} \; 0.3 = .000185"$$

$$a_4 = 0.006 \sqrt{4000} = 0.38$$

$$p_4 = \frac{2 \times 4}{\pi \times .19} = 13,400$$

$$w_4 = \frac{.7 \times 13,400}{24 \times 10^6} \times 0.19 = .000074$$

Δ due to load at 4 = .000237

" " " 3 = .000405

" " " 2 = .000443

" " " 1 = .000184

" " " 0 = 0

.001369 +.000074 = .001343

stress in web due to load at				0 = 4,570
"	"	"	"	1 = 8,050
"	"	"	"	2 = 6,050
"	"	"	"	3 = 4,770
"	"	"	"	4 = 1,900
				25,340 lb.per sq.in.

The stress is all right but the distribution of load is in error. The deflectinn at M_2 is too great; put heavier loads near the web.

Assume this distribution of load:

4	3	2	1	0	1	2	3	4	
0	0	5	11	28	11	5	0	0	$=60^k$

$$a_o = 0.006\sqrt{38,000} = 1,001$$

$$p_o = \frac{2 \times 38,000}{\pi \times .5} = 37,000$$

$$w_o = \frac{7 \times 37000}{2 \times 12 \times 10^6} \times .50 = .000540$$

$$a_4 = 0.006\sqrt{5000} = .434$$

$$p_2 = \frac{2 \times 5000}{\pi \times .212} = 15,000$$

$$w_2 = \frac{7 \times 15,000}{2 \times 12 \times 10^6} \times .212 = .000093$$

$$.000460$$

$$.000553$$

Δ due to load at		0 =	.0
" "	"	1 =	.000214
" "	"	2 =	.000246

.000460 + .000093 = .000553

stress due to load at			0 =	12800
"	"	"	1 =	19320
"	"	"	2 =	3360
				35480

It is seen that very light loads at load point 4 cause more deflection than is allowed by the depth of the impression at the web. Evidently there can be no load at point 4. Now, since that point carries no load it may deflect clear away from the roller. In the computations, check the deflection at point M1 against the depth of impression at load point 0.

It is found that a total load of 80,000 pounds distributed thus:

4	3	2	1	0	1	2	3	4
0	0	5	11	38	11	5	0	0

can be safely carried by the section.

It is evident that a section with these dimensions is not of great value as a sole plate. If the flange had been thicker, the section would have been strengthened a great deal. The recommendation of Professor Wilson for flange thickness is 1" + 0.004D which in this problem is 1.9".

This problem in itself is only of academic value but the method of attack of the problem may be of some value to the designer of sole plates for rolling lift bridges.

Strains were measured in the web to determine the accuracy of the assumed stress distribution.

Two Huggenberger Tensometers, one on either side of the web, were used to make the measurements of strain in the web for loads on the flange. The tensometer is shown by photograph in Fig. 47.

It is a so-called "fixed instrument". The gage points are knife edges which engage firmly in the material by the force of the clamps which hold the instrument in place. The multiplication ratio of one instrument was 1063 while of the other was 1302. The scale was divided into tenths and readings were estimated to hundredths. One division on the scale represented a change of the gage length of less than 0.001 inch. The size and consistency of the readings indicate they were fairly precise and represented the strains.

It is possible to vary the gage length of the instrument by changing the fixed knife edge. With a gage length of 1-5/8 , the fixed knife edge engaged the web about 1/32 inch from the flange. An influence line for strain on a 1-5/8 inch gage length at the vertical center line of the web was drawn. By changing the gage length to 1 inch and keeping the movable knife edge in the same place, another influence line for strain on a 1 inch gage line was drawn. The difference between the total strain in the two cases is the strain on a 5/8 inch gage line next to the flange.

The stress in the web was computed from these values of strain assuming E = 30,000,000 pounds per square inch. The computations are given in Table 6.

The values of stress thus determined are shown in Figure 44 with the assumed values.

Fig. 47

Huggenberger Tensometer

For Measuring Strain in Web of a Steel Casting having an H-Section

TABLE VI. TENSOMETER READINGS AND STRESS CALCULATIONS.

	Load At	Zero Reading N	Zero Reading S	Loaded Reading N	Loaded Reading S	Difference N	Difference S	Increment in Load	Difference in Reading per Unit of load. N	Difference in Reading per Unit of load. S	Total Strain per Unit of Load x10^{-4} N	Total Strain per Unit of Load x10^{-4} S	Average Strain x 10^{-4}
$1\frac{5}{8}$" gage length.	0	.470	.455	.320	.240	.150	.215	8.2^k	.0183	.0262	.1718	.2180	.1949
	1	.410	.400	.095	.060	.315	.340	15.1	.0208	.0225	.1953	.1872	.1912
	2	.440	.400	.130	-.010	.310	.410	20.	.0155	.0202	.1455	.1680	.1567
	3	.450	.440	.150	.145	.300	.295	20.2	.0148	.0146	.1390	.1216	.1303
	4	.460	.450	.215	.200	.245	.250	20.0	.0122	.0125	.1146	.1040	.1093
	5	.490	.445	.345	.155	.145	.290	20.0	.00725	.0145	.06808	.1206	.09434
	6	.485	.465	.290	.290	.195	.175	20.2	.00966	.00868	.09071	.07221	.08146
	7	.490	.485	.310	.325	.180	.160	20.4	.00884	.00785	.08301	.06530	.07415
	8	.480	.450	.380	.250	.100	.200	20.0	.00500	.0100	.04695	.08319	.06507
	9	.485	.455	.390	.290	.095	.165	20.0	.00475	.00825	.04460	.06863	.05661
1" gage length.	0	.400	.855	.300	.720	.100	.135	10.1	.00990	.0134	.09296	.11147	.10221
	1	.390	.810	.200	.555	.190	.255	20.0	.00950	.01275	.08921	.10607	.09764
	2	.385	.825	.215	.600	.170	.225	20.1	.00846	.01120	.07944	.09317	.08630
	3	.400	.840	.260	.635	.140	.205	20.2	.00694	.01017	.06516	.08460	.07488
	4	.410	.845	.300	.650	.110	.195	20.3	.00542	.00960	.05089	.07986	.06537
	5	.405	.845	.295	.675	.110	.170	20.2	.00545	.00843	.05118	.07013	.06065
	6	.400	.850	.290	.705	.110	.145	20.0	.00550	.00725	.05165	.06031	.05598
	7	.405	.850	.300	.710	.105	.140	20.1	.00523	.00697	.04911	.05798	.05354
	8	.410	.845	.350	.675	.060	.170	20.0	.00300	.00850	.02817	.07071	.04944
	9	.380	.830	.300	.700	.080	.130	20.0	.00400	.00650	.03756	.05407	.04581

Load at	Strain in 5/8"x10^4	Unit Strain x 10^{-4}	Stress/kip. E=30000000
0	.0927	.1483	444.9
1	.0936	.1498	449.4
2	.0704	.1126	337.8
3	.0554	.08864	265.9
4	.0439	.07024	210.7
5	.0337	.05392	161.8
6	.0255	.04080	122.4
7	.0206	.03296	98.9
8	.0156	.02496	74.9
9	.0108	.01728	51.8

PART II.

IV. THE CARRYING CAPACITY OF STEEL CASTINGS HAVING SPECIAL SHAPES.

IV. THE CARRYING CAPACITY OF STEEL CASTINGS HAVING SPECIAL SHAPES.

1. Foreword. The objection that sole plates having a rectangular section contain much idle metal is applicable to a sole plate having an H-section. Only that metal at the critical section in either case is stressed to the allowable. The critical section in a rectangular plate is at a small depth from the rolled surface. The critical section in a sole plate having an H-section is in the web next to the flange. The remainder of the metal is understressed.

A plate with a cross section which varies with the depth seems to be one in which more of the metal is stressed nearer the allowable.

This study was undertaken to:

a. Compare the carrying capacity of special shaped steel castings with castings having a solid rectangular section.

b. Study the effect of the properties of the material on the carrying capacity of the plate.

c. Study the distribution of strain in a deep casting having a rectangular section.

Rolling tests were made on castings having a V-shaped top flange with and without stiffeners, also on castings having solid rectangular sections. Each shape was made of two materials, carbon steel casting and high manganese steel casting under the trade name of Hylastic Steel. Two depths of rectangular plates were tested,

vis. $1\frac{1}{2}$ inches and $4\frac{3}{4}$ inches. The diameter of roller was 236 inches in all tests.

3. Description of Test. Figure 48 shows the dimensions and shape of each specimen. The castings of Hylastic steel are denoted by the additional letters HYL. The Foundry gave the chemical properties as follows:

	C	S	Si	Mn	P
Carbon Steel Casting	0.30	0.35	0.35	0.70	0.02
Hylastic " "	0.35	0.03	0.40	1.45	0.02

The physical properties are as follows:

	Yield Point	Ultimate Strength	Reduction of Area	Elongation in 2 inches
Carbon Steel Casting	43500	79500	38.7	33.1
Hylastic Steel Casting	57660	103200	42.8	22.8

All the specimens were normalized at the Foundry and received no heat treatment in the laboratory. They were separate castings large enough that $\frac{1}{4}$ inch of material could be removed from all finished surfaces in finishing the specimen. The rolled surfaces were finished by hand with a file and emery cloth and proved with a machinist's face-plate.

The apparatus used for these tests was that used by Professor Wilson in his study of large rollers and is described on page 14.

The procedure of testing is described on page 34 except that the specimen was rolled 2000 strokes at each load instead of 1000.

Measurements were made for lateral and longitudinal flow as described on page 23. In addition, vertical deformations were measured on a 4 inch gage length. In specimens C31 and HYLC31,

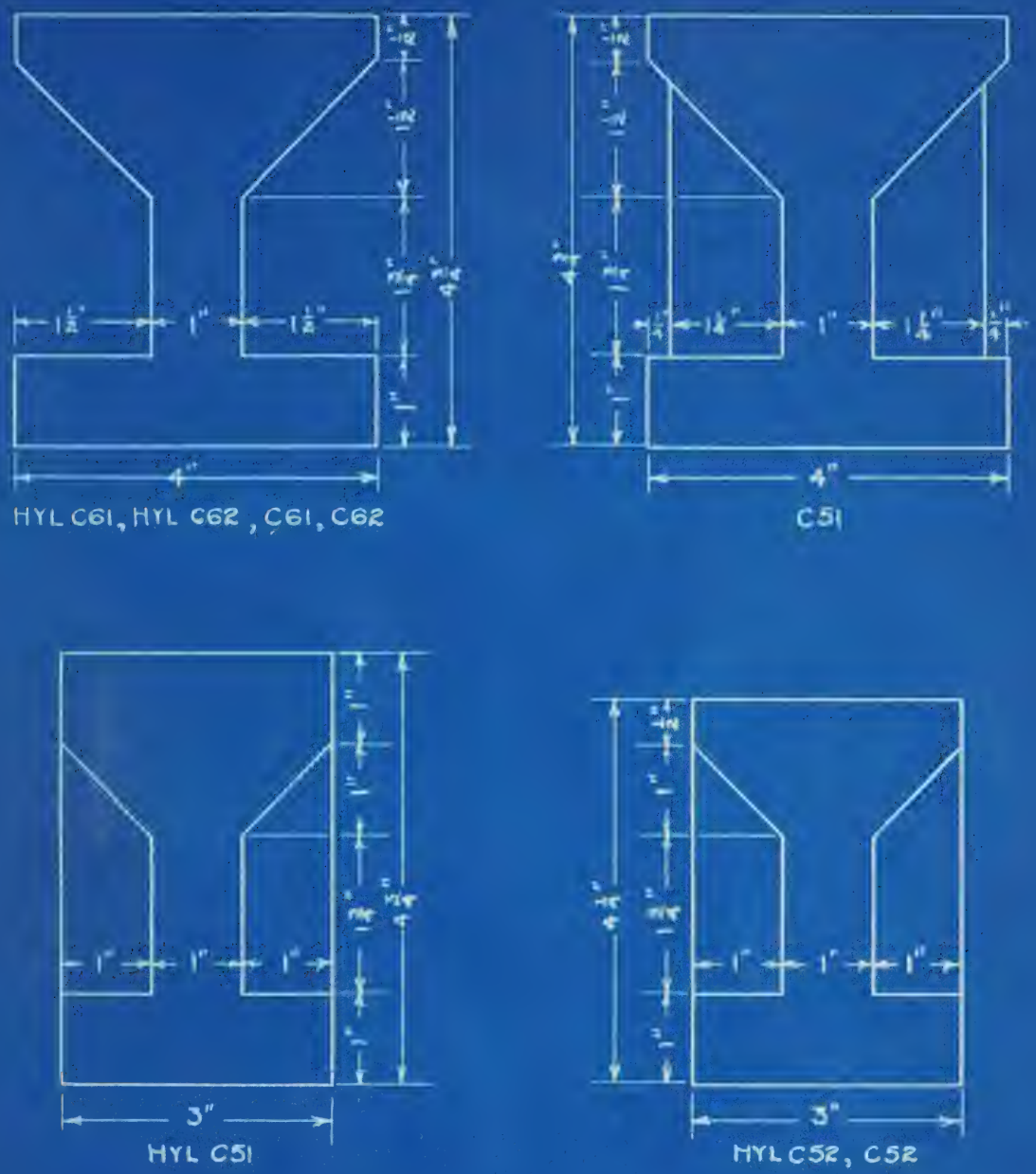


Fig. 48

Shape and Dimensions
of
SPECIAL SHAPED CASTINGS

vertical deformations were also measured on a 2" gage length.

3. Results. The results of these tests are shown in Figures 49 to 68 inclusive. The critical load is considered to be that at the break in the curve as at point a Figure 51a.

C31 and HYI C31. These plates had solid rectangular sections 4 inches wide and $4\frac{1}{4}$ inches thick. The load-deformation curves are given in Figures 49 and 50.

The curve for test C31 indicates that the maximum lateral flow occurred at the top of the plate and that very little flow occurred lower than 1/8th the depth of the block or 5/8 inch below the surface. The test on HYI C31 was not carried far enough to determine the critical load.

The unit vertical deformation in the top 2 inches is only slightly more than that in the top 4 inches.

The longitudinal flow in neither case was very great and does not give a critical load.

The critical load for C31 determined by lateral flow is 61000 pounds per inch width of plate and from vertical deformation it is 64000 pounds per inch width of plate.

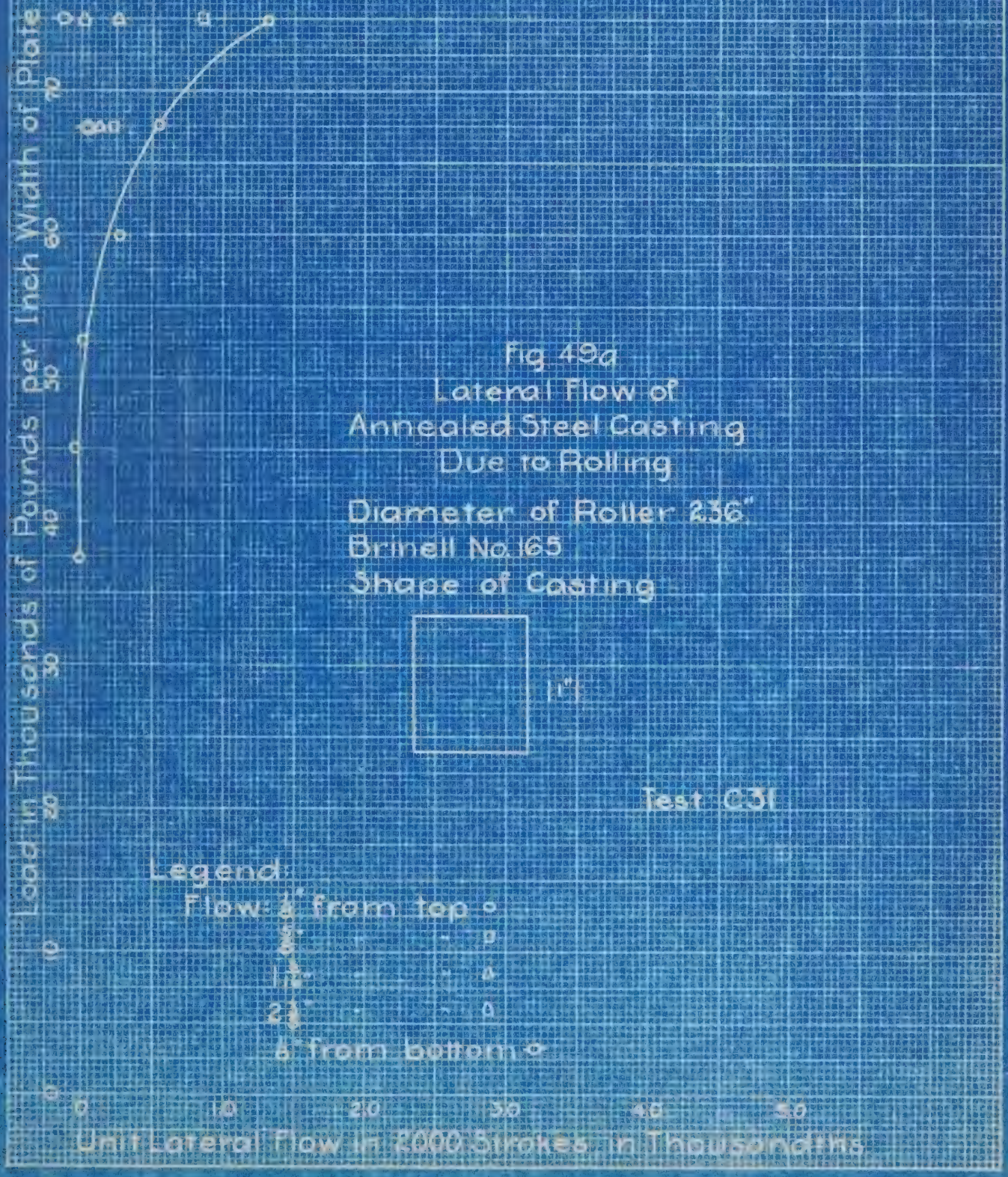
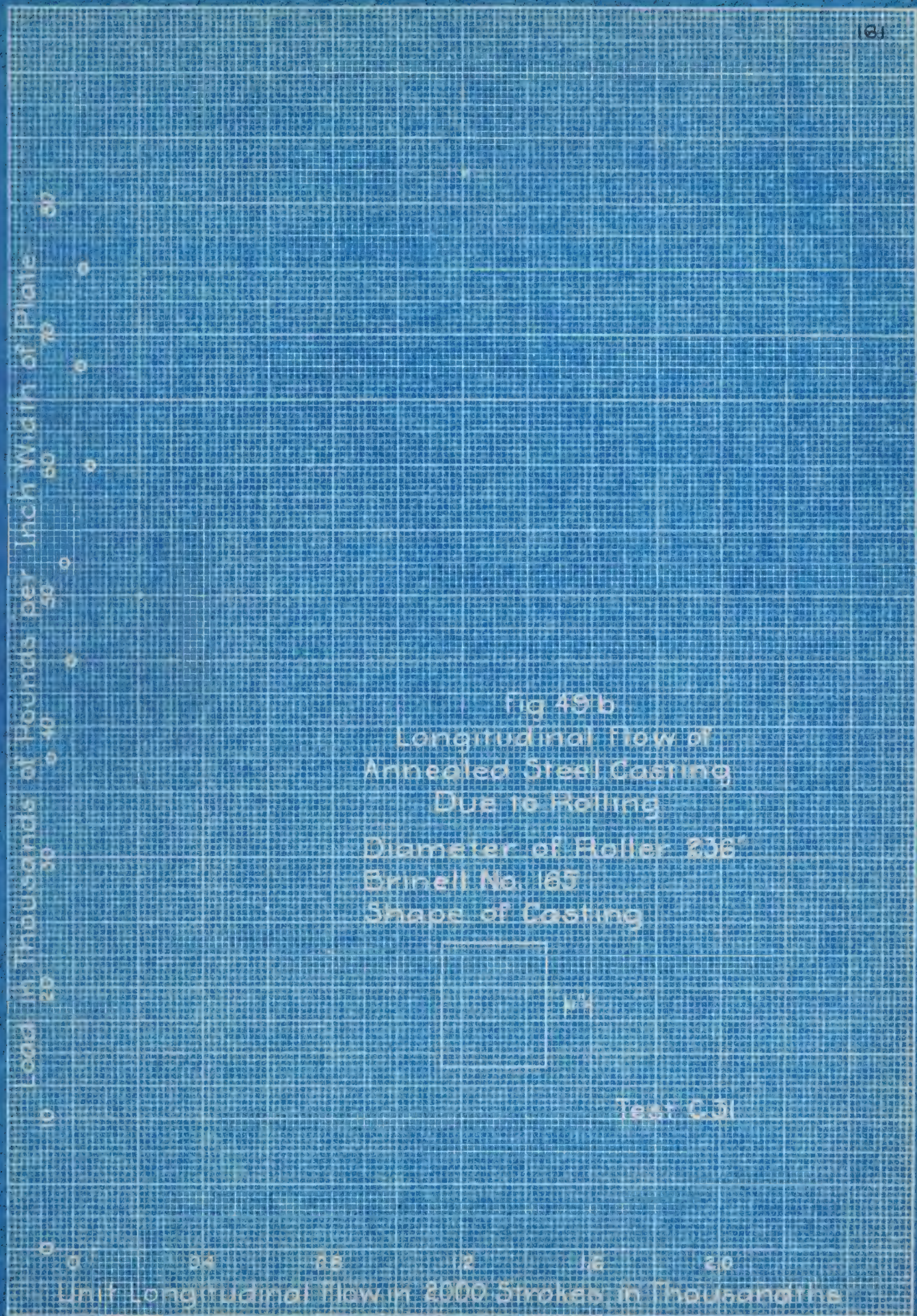


Fig 49a
Lateral Flow of
Annealed Steel Casting
Due to Rolling
Diameter of Roller 236"
Brinell No. 165
Shape of Casting
Test Col
Legend
Flow 4 from top
2 from bottom
Load in Thousands of Pounds per Inch Width of Plate
Unit Lateral Flow in 2000 Strokes in Thousand Ins


Longitudinal Flow of Annealed Steel Casting
Due to Rolling
Diameter of Roller 206"
Brinell No. 165
Shape of Casting
Fig. 49 b
Fig. 49 a
Unit Long Quarter Flow in 2000 Strokes in Thousandths

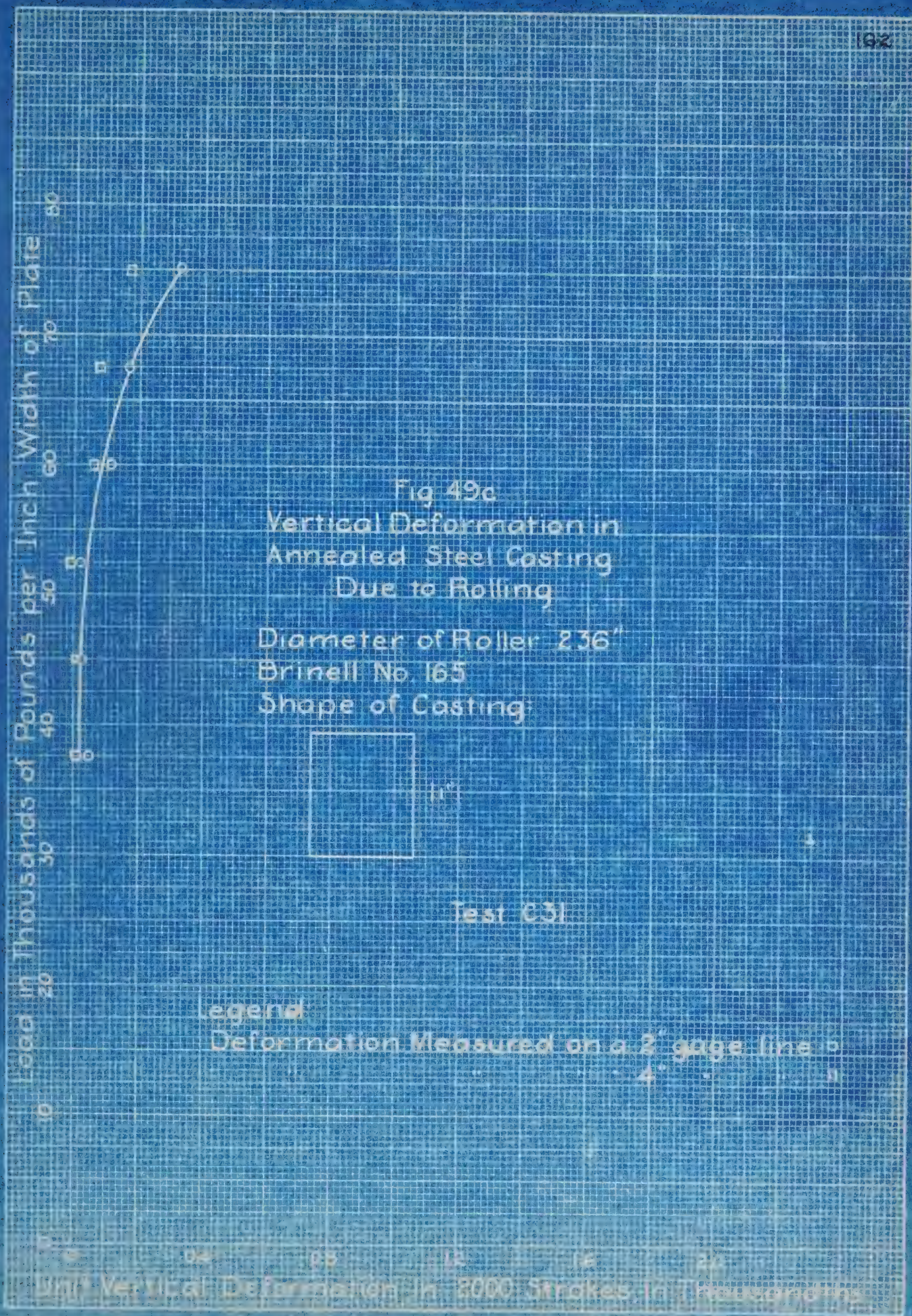


Fig 49c
Vertical Deformation in
Annealed Steel Casting
Due to Rolling
Diameter of Roller 236"
Brinell No. 165
Shape of Casting
Test C31
Legend
Deformation Measured on a 2" gage line
Load in Thousands of Pounds per Inch Width of Plate
Unit Vertical Deformation in 2000 Strokes in Thousands

Fig 50a
Lateral Flow of
Mylastic Steel Casting
Due to Rolling

Diameter of Roller 2.36"
Brinell No. 214
Shape of Casting

164

Fig. 50b

Lateral Fluid Flow of

Hydrostatic Steel Casting

Due to Rolling

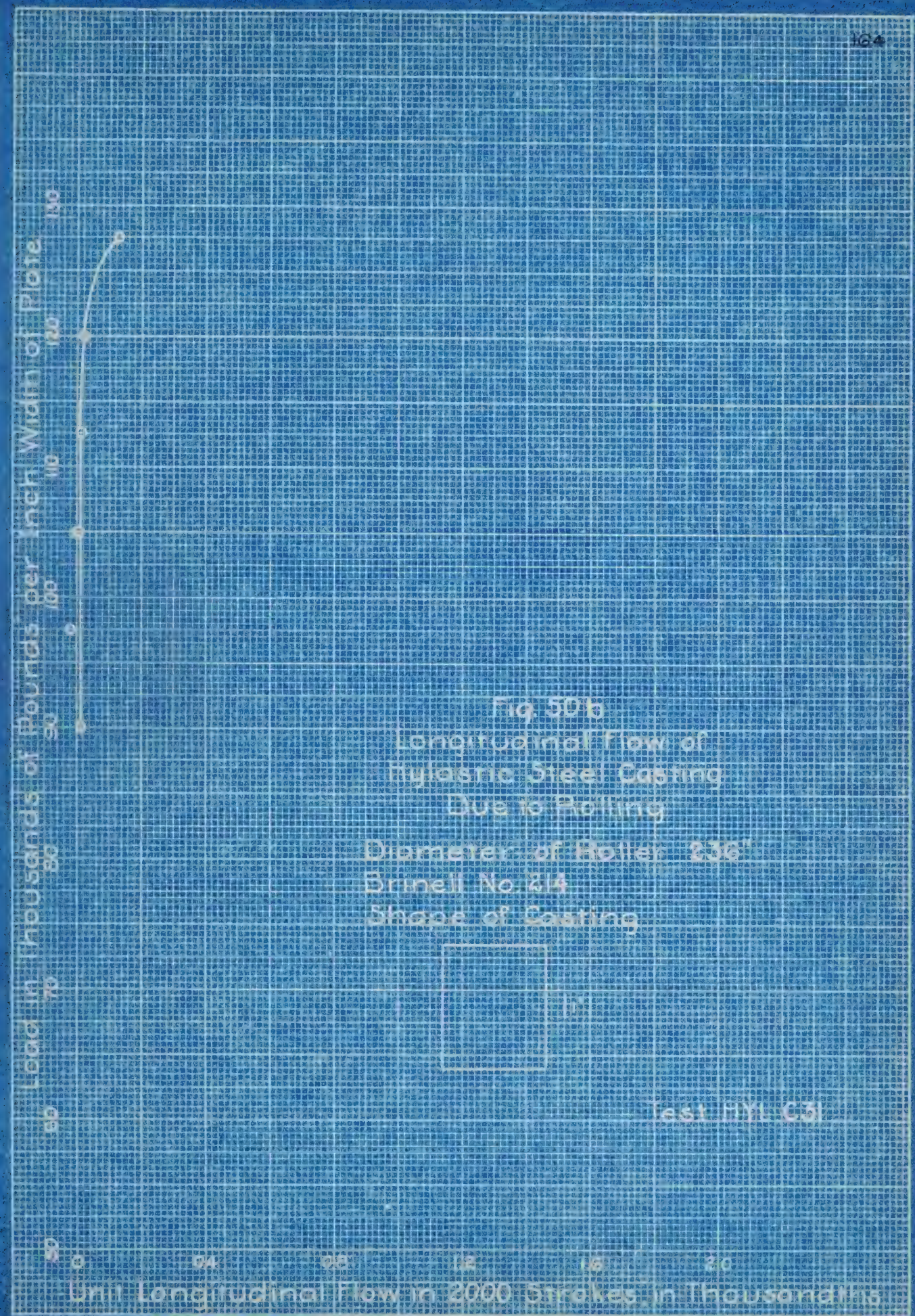
Diameter of Roller 2.5"

Drunell No. 414

Shape of Casting

Test Pieces

Unit Lateral Fluid Flow in 2000 Strokes in Thousands



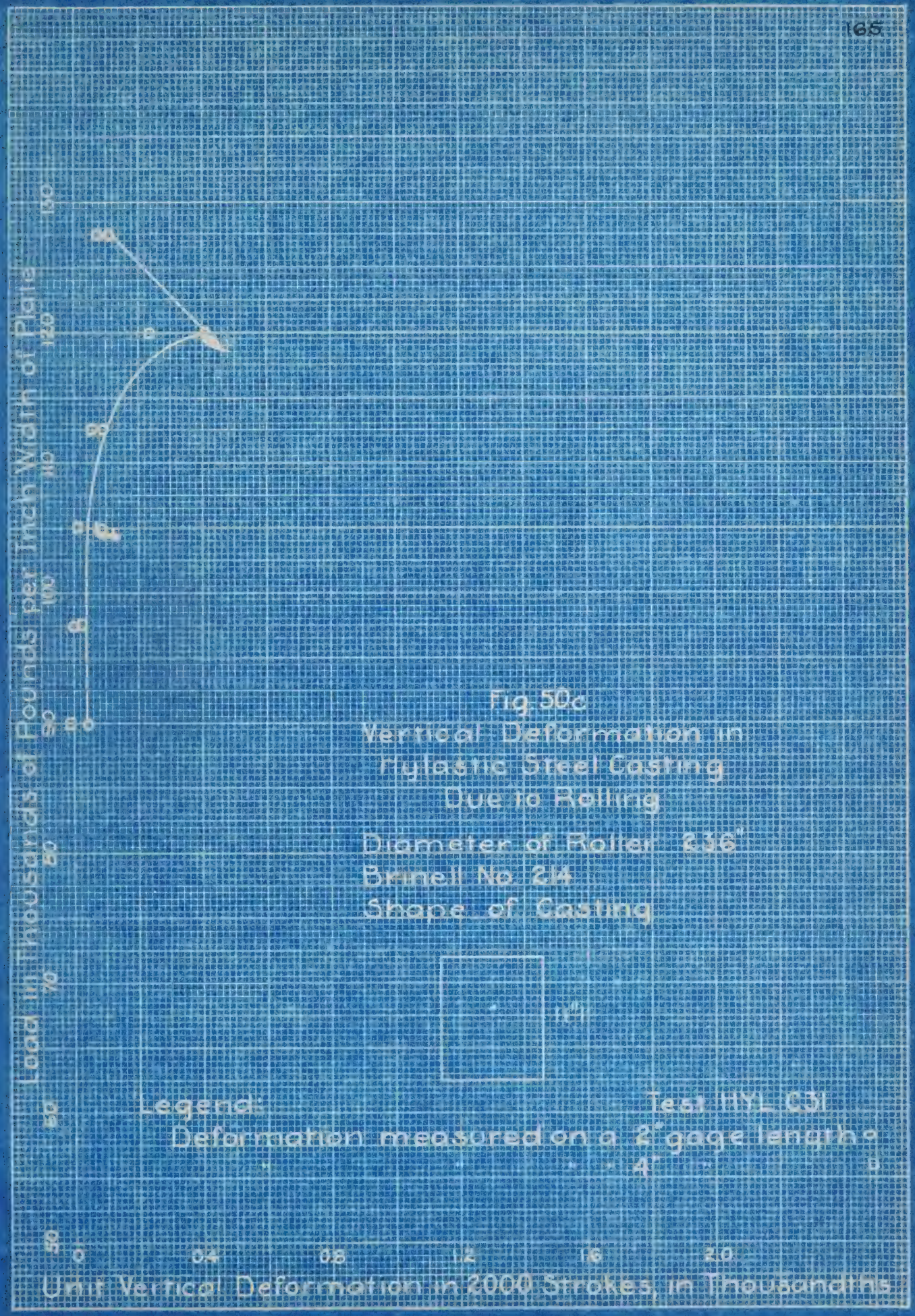


Fig. 50c
Vertical Deformation in
Tuylagne Steel Casting
Due to Rolling

Diameter of Roller 6 1/16"
Brinell No. 214
Shape of Casting

<u>C41, C42, HYL C41, and HYL C42.</u> These specimens had solid rectangular sections 4 inches wide and 1½ inches thick. The load-deformation diagrams are given in Figures 51 to 54.

The critical load from the lateral flow of C41 and C42 is 60,000 pounds per inch of width of plate.

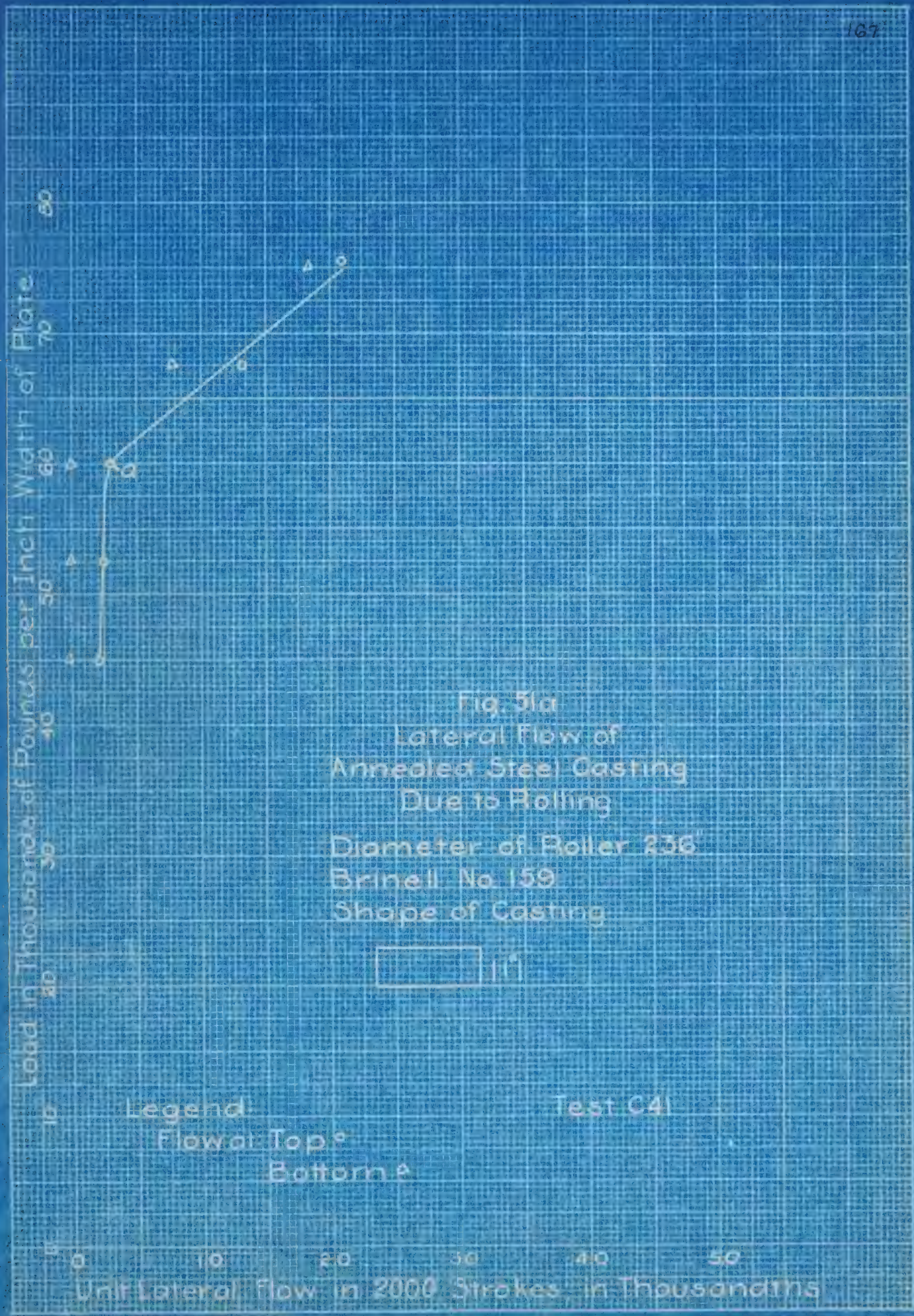
The critical load from the longitudinal flow of C41 and C42 is 61500 pounds per inch of width of plate.

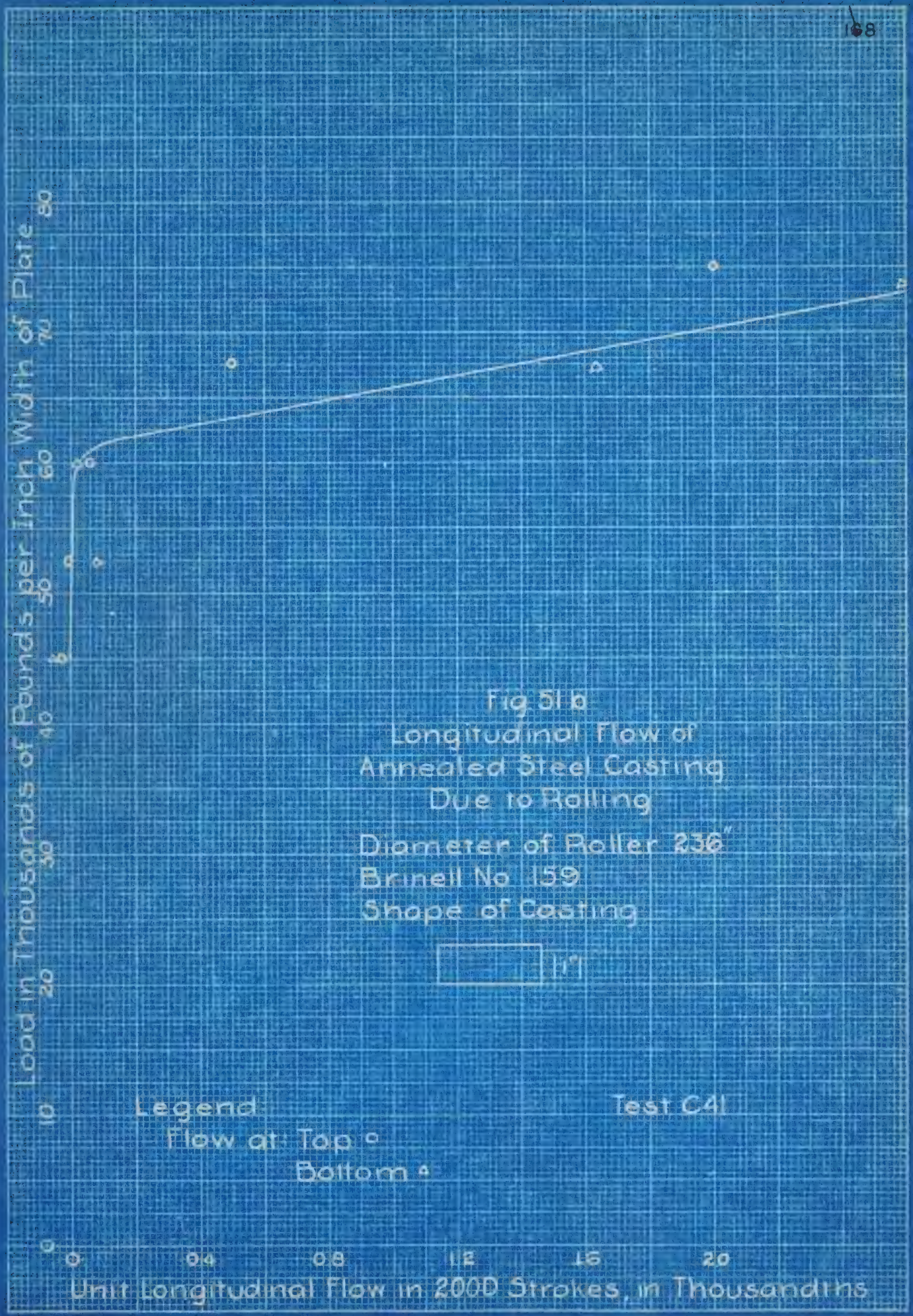
The critical load from the lateral flow of HYL C41 is 104,000 pounds per inch width of plate while from HYL C42 it is 110,500 pounds per inch of width.

The critical load from the longitudinal flow of HYL C41 is 101,000 pounds per inch width of plate while from HYL C42 it is 108,000 pounds per inch of width.

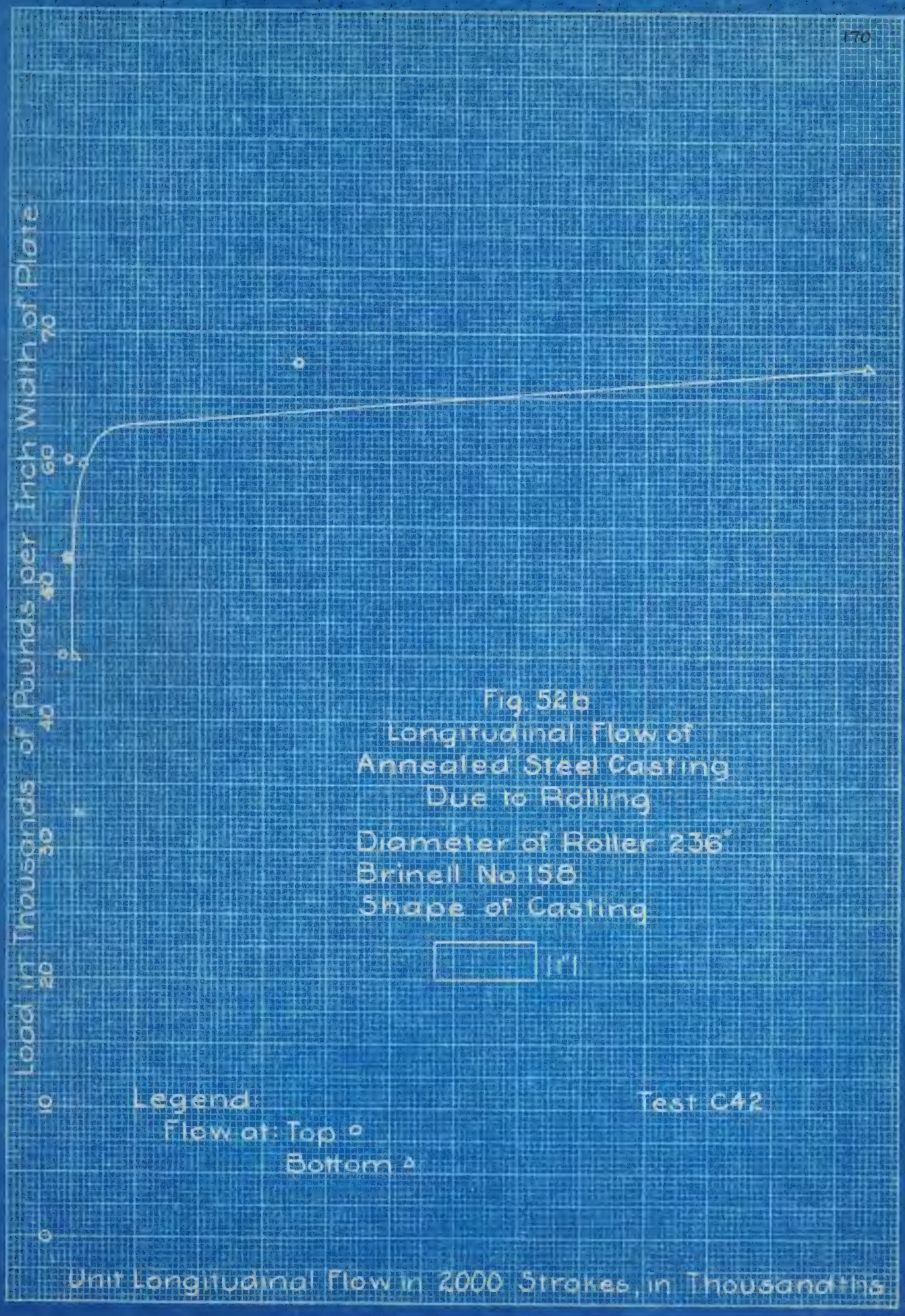
These values of critical load compared with the following results obtained by Professor Wilson with material of different grades tested in the same manner indicate that the grade of the material has a marked effect on the bearing value of a plate.

Carbon Steel Casting (annealed)	45,500	lb.	per in.	of width.
" " " (hardened)	90,000	"	"	"
Structural Steel	22,300	"	"	"


Load in Thousands of Pounds per Inch Width of Plate
10
20
30
40
50
60
70
80
Fig. 51a
Lateral Flow of
Annealed Steel Casting
Due to Rolling
Diameter of Roller 2.36"
Brinell No 159
Shape of Casting
Legend
Flow at Top ○
Bottom △
Test C41
0
10
20
30
40
50
Unit Lateral Flow in 2000 Strokes in Thousandths


Load in Thousands of Pounds per Inch Width of Plate
0
10
20
30
40
50
60
70
80
Unit Longitudinal Flow in 2000 Strokes, in Thousandths
0
0.4
0.8
1.2
1.6
2.0
Fig 51 b
Longitudinal Flow of
Annealed Steel Casting
Due to Rolling
Diameter of Roller 23.6"
Brinell No 159
Shape of Casting
11"
Legend
Flow at Top
Bottom
Test C41

Load in Thousands of Pounds per Inch Width of Plate
0
10
20
30
40
50
60
70
0
10
20
30
40
50
Unit Lateral Flow in 2000 Strokes in Thousandths
Fig 52a
Lateral Flow of
Annealed Steel Casting
Due to Rolling
Diameter of Roller 2.36"
Brinell No 158
Shape of Casting
Legend
Flow at Top o
Bottom Δ
Test C42


Load in Thousands of Pounds per Inch Width of Plate
0
10
20
30
40
50
60
70
Unit Longitudinal Flow in 2000 Strokes, in Thousandths
Legend:
Flow at: Top ○
Bottom △
Test C42
Fig. 52b
Longitudinal Flow of
Annealed Steel Casting
Due to Rolling
Diameter of Roller 23.6"
Brinell No 158
Shape of Casting
1"

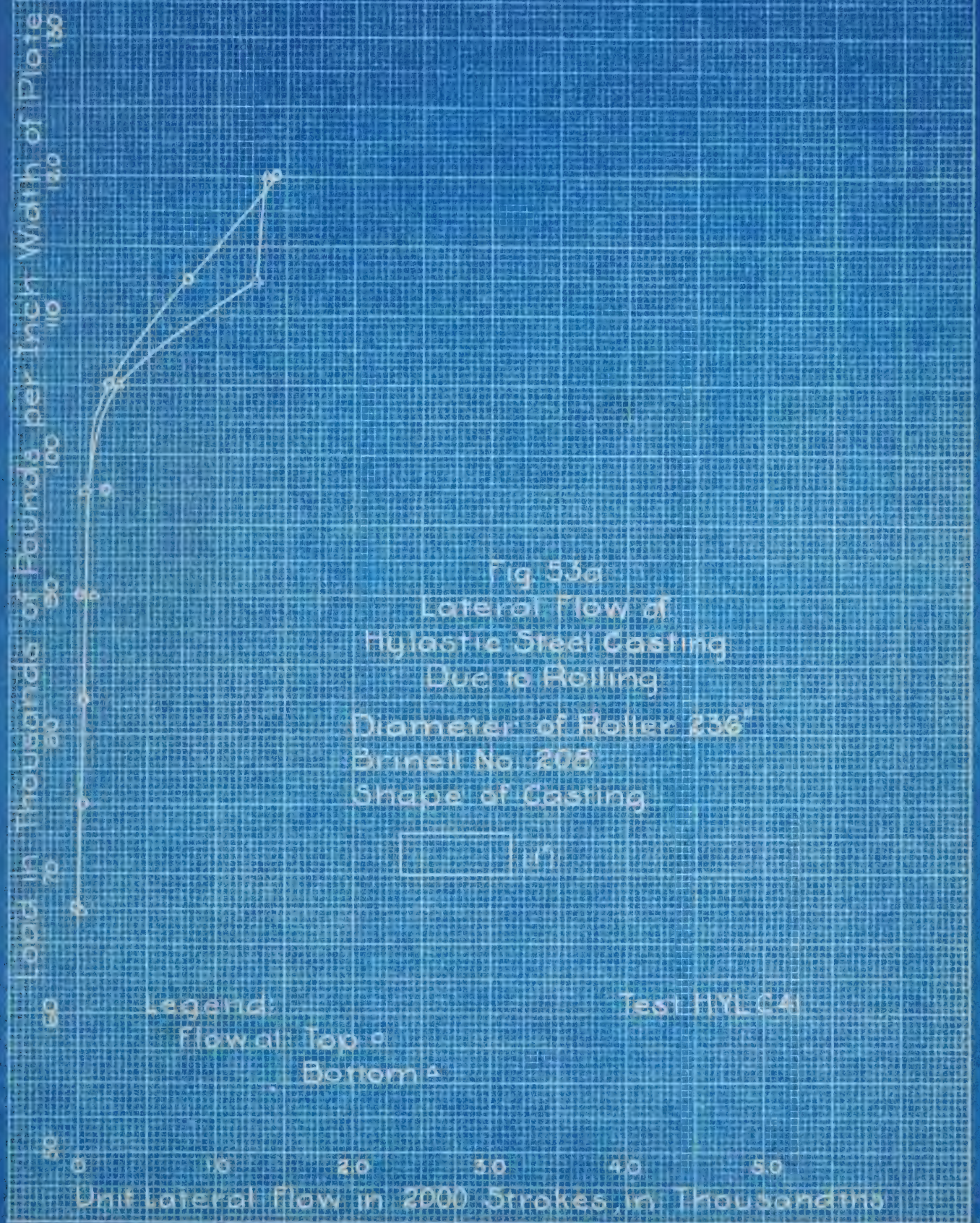


Fig. 53a
Lateral Flow of
Hylastic Steel Casting
Due to Rolling
Diameter of Roller 2.56"
Brinell No. 206
Shape of Casting

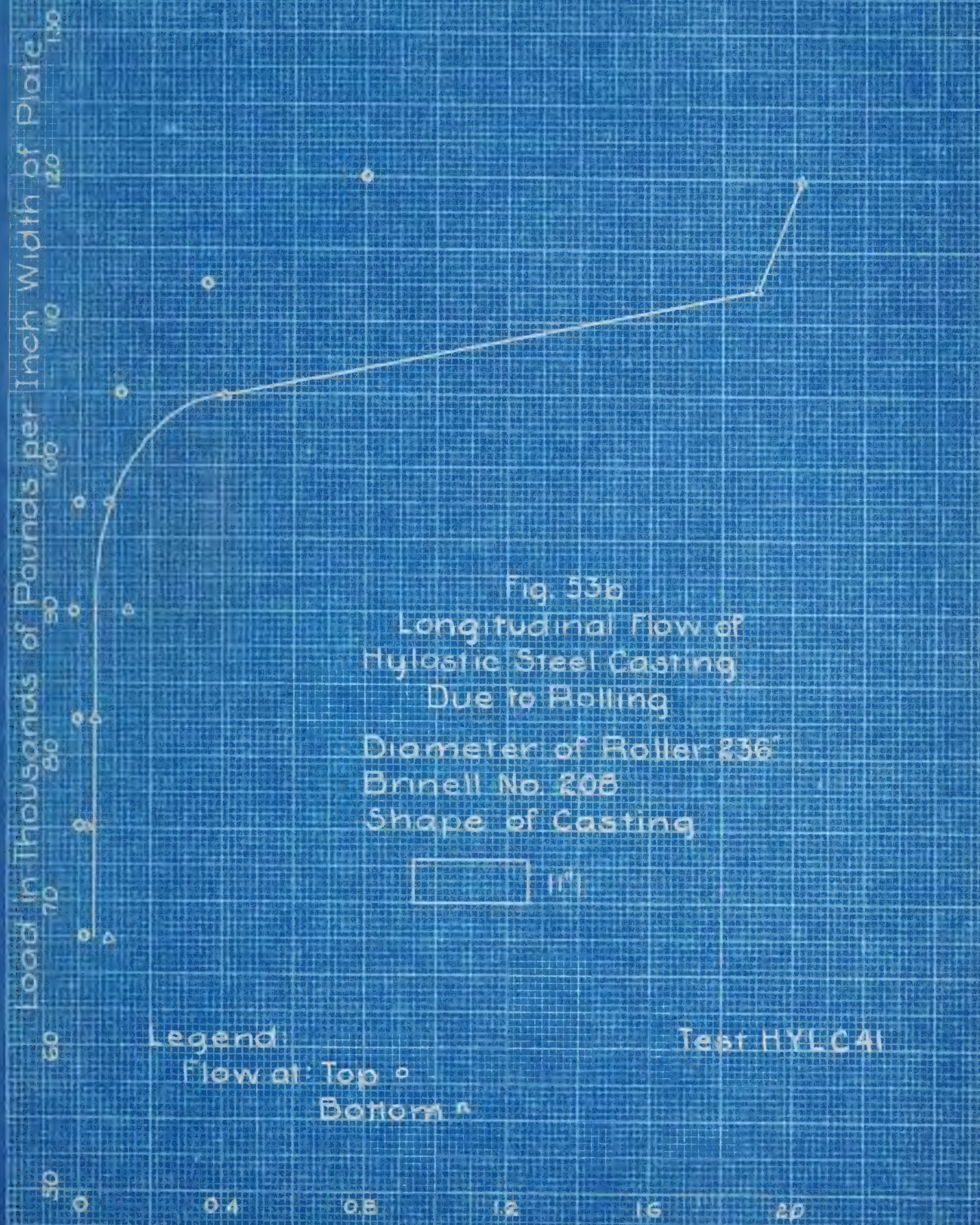
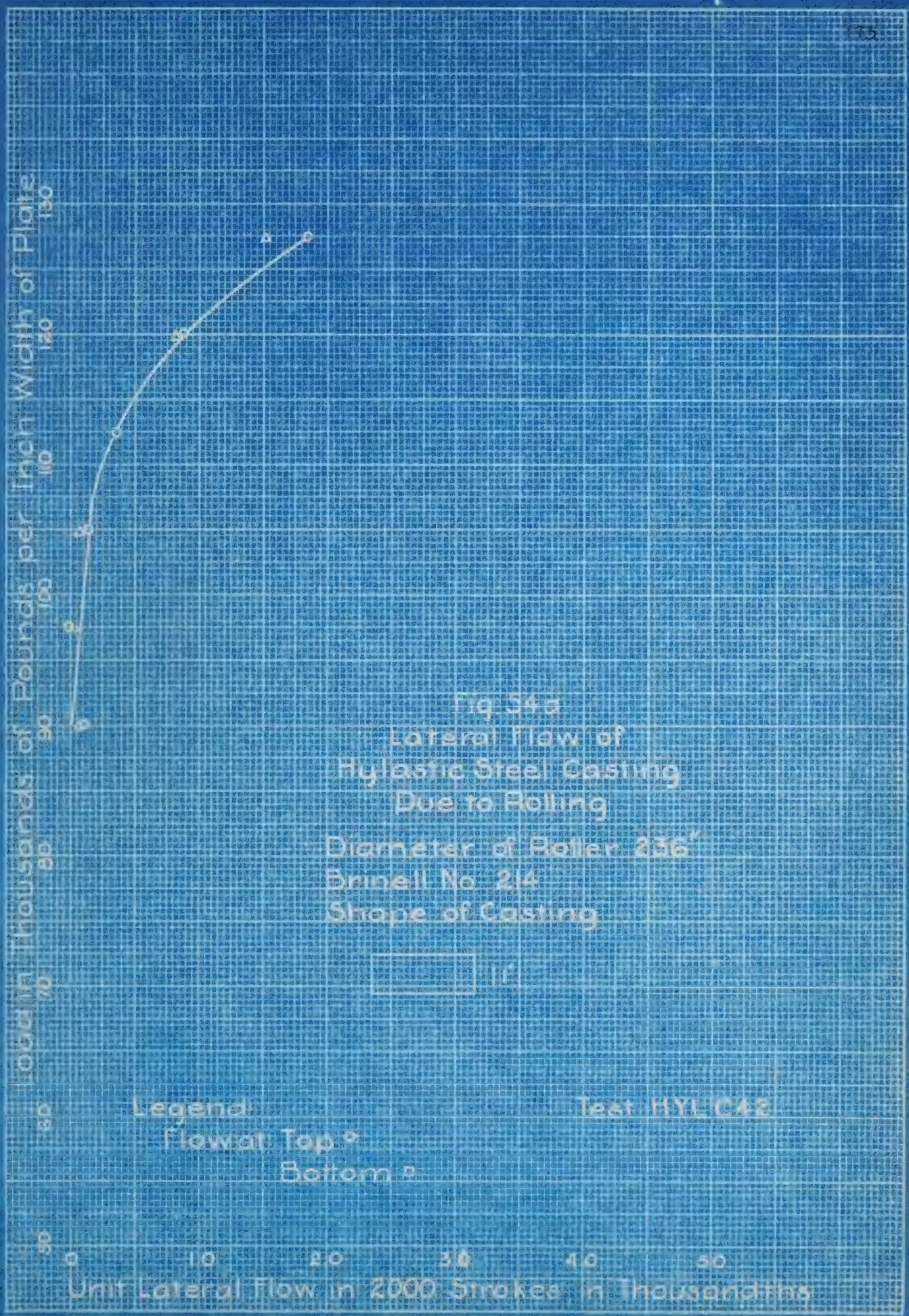


Fig. 53b
Longitudinal Flow of
Hylastic Steel Casting
Due to Rolling

Diameter of Roller 8.36"
Brinell No. 208
Shape of Casting


Lateral Flow of
Hydrostatic Steel Casting
Due to Rolling
Diameter of Roller 2.36"
Brinell No. 214
Shape of Casting
Legend
Flow at Top
Bottom
Test HYL-C42
0
10
20
30
40
50
Unit Lateral Flow in 2000 Strokes in Thousandths

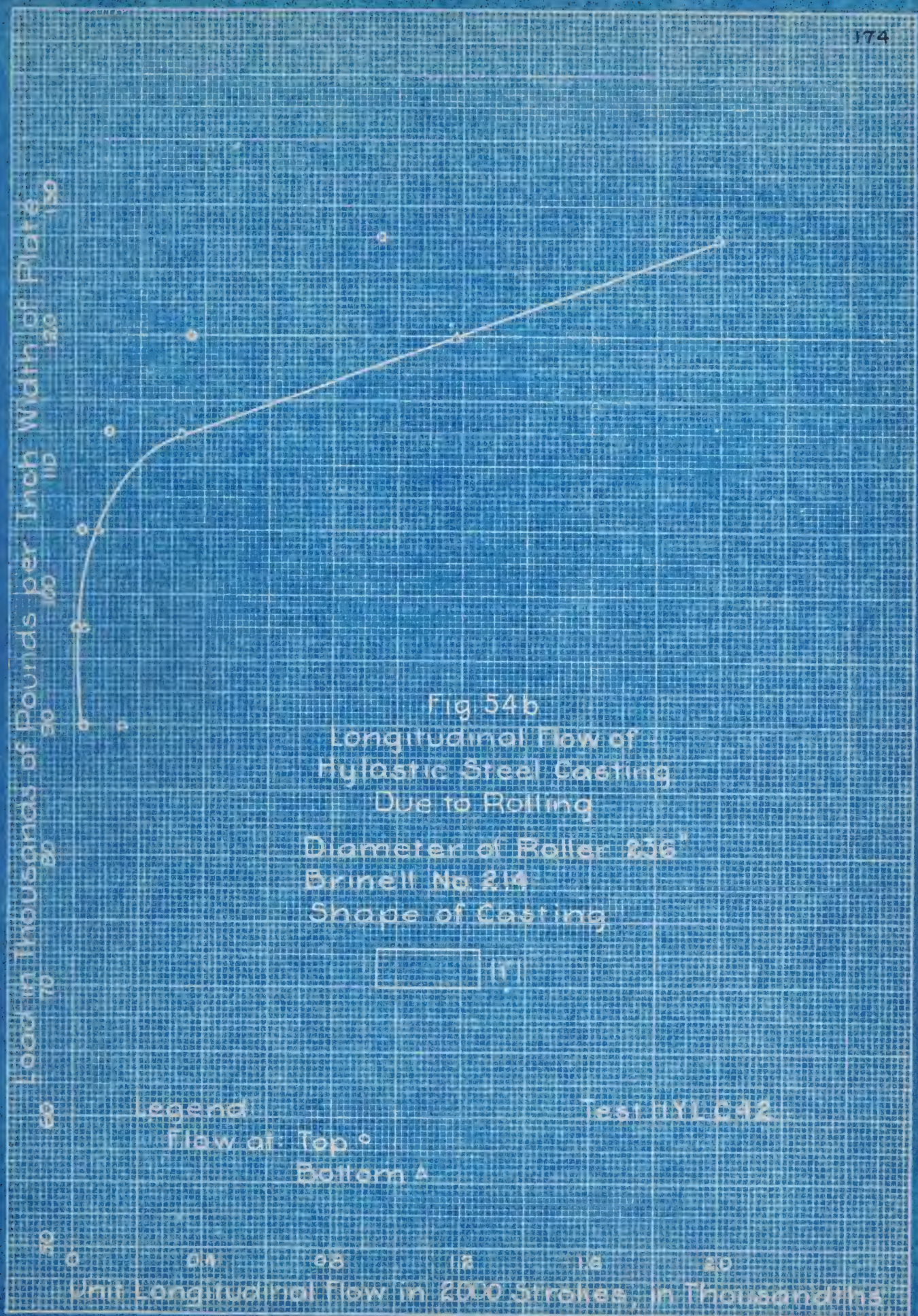


Fig 54b
Longitudinal Flow of
Hydraulic Steel Casting
Due to Rolling
Diameter of Roller 236
Brinell No 214
Shape of Casting

C51, C52, HYL C51 and HYL C52. The shapes and dimensions of these specimens are given in Figure 45. It will be noticed that HYL C52 and C52 have the same section and that HYL C51 and C51 are still different. The load deformation curves are shown in Figures 55 to 58 inclusive.

The critical loads are as follows:

Specimen	From Longitudinal Flow	From Lateral Flow	From Vertical Flow
C51	45000	42500	31000
C52	41500	40000	39000
HYL C51	92000	89000	70000
HYL C52	73000	73000	57000

The cross-sectional area of the web is 12 square inches. The total load on C51 at the critical load from vertical deformation is 124000 pounds, while C52 carried 117000 pounds. The average unit stress in C51 was 10,300 pounds per square inch and in C52 it is 9750 pounds per square inch.

The cross-sectional area of the web of the Nylastic specimens is 12 square inches. The total load carried by HYL C51 at the critical load for vertical deformation is 210,000 pounds while HYL C52 carried only 171,000 pounds. The average unit stresses are 17,500 pounds per square inch and 14,200 pounds per square inch respectively.

Since deformation depends on the maximum stress and not the average stress, it seems that the heavier flange of HYL C51 distributed the load to the web more uniformly than the flange of

HYL C52. This is also brought out by the slightly higher average stress in C51 than in C52.

The vertical pressure on sections parallel to the surface and at various depths is shown in Figures 59 to 62. They were calculated on the assumption that the stress is distributed uniformly on a length of plate equal to the width of area in contact plus the depth from the surface.

These values of the vertical pressure indicate that the material is overstressed.

The pressure on the web calculated by this assumption is about the same in HYL C51 as in HYL C52. The total load carried by HYL C51 with a heavier flange is 39000 pounds more than carried by HYL C52.

Specimen C52 is more highly stressed than C51, according to these calculations, although C51 carried the greater total load but also had a heavier flange.

The lateral and longitudinal flows in C51 and C52 show critical loads at nearly the same load per inch of width, while in HYL C51 and HYL C52 the critical loads are quite different. In the first pair of specimens, the flanges were similar while in the second pair one was ½ inch thicker than the other, the thicker one indicating the higher critical load.

The critical load from vertical flow is lower than from either lateral flow or longitudinal flow indicating that the web is the weakest section.

The critical loads from vertical deformation for C31 and C51 are 64000 and 31000 pounds per inch width of plate respectively.

This indicates that by cutting part of the material out of the solid rectangular section making this special shaped casting the carrying capacity is greatly decreased.

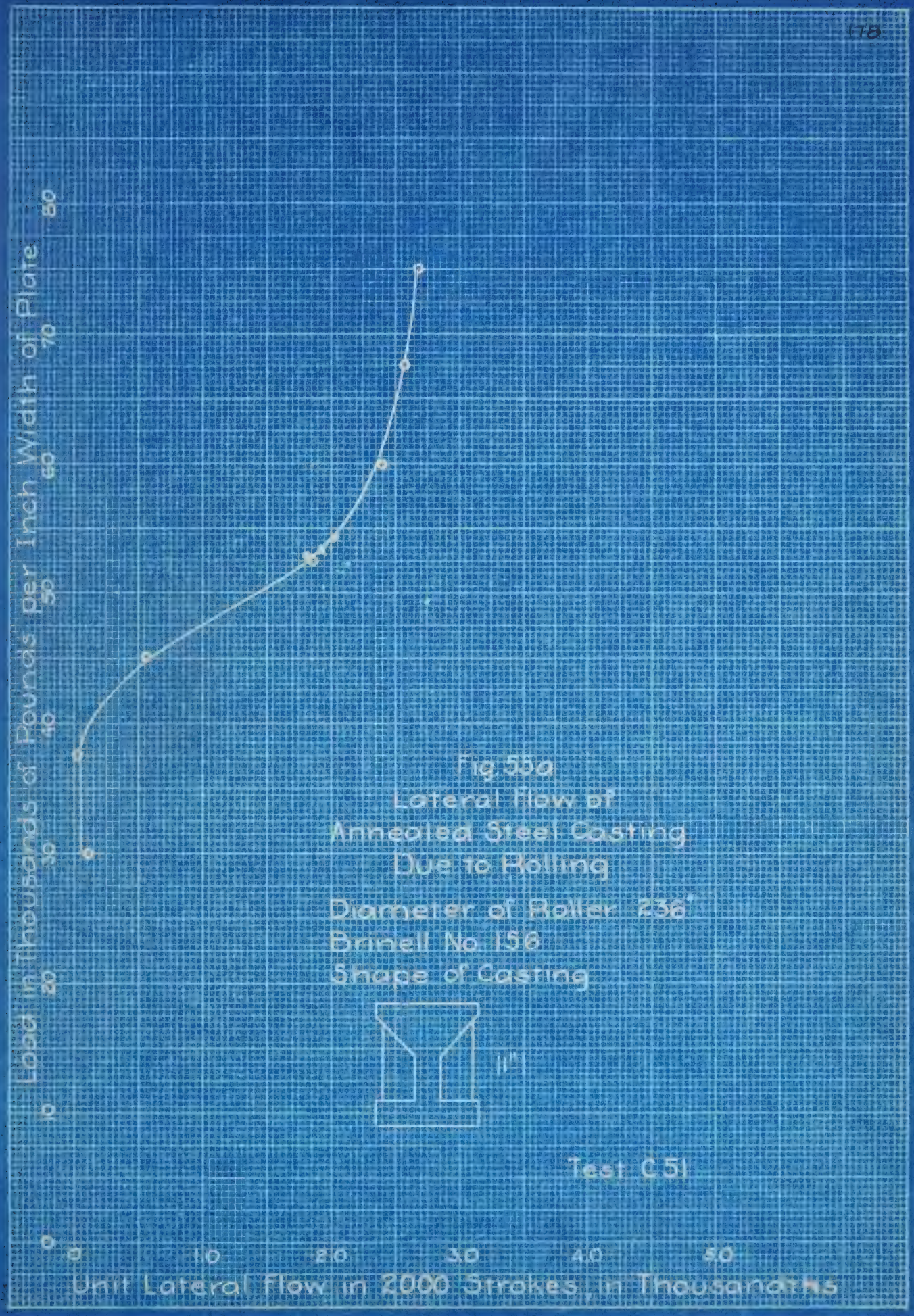


Fig 5aa
Lateral Flow of
Annealed Steel Casting
Due to Rolling
Diameter of Roller 2.36"
Brinell No. 156
Shape of Casting

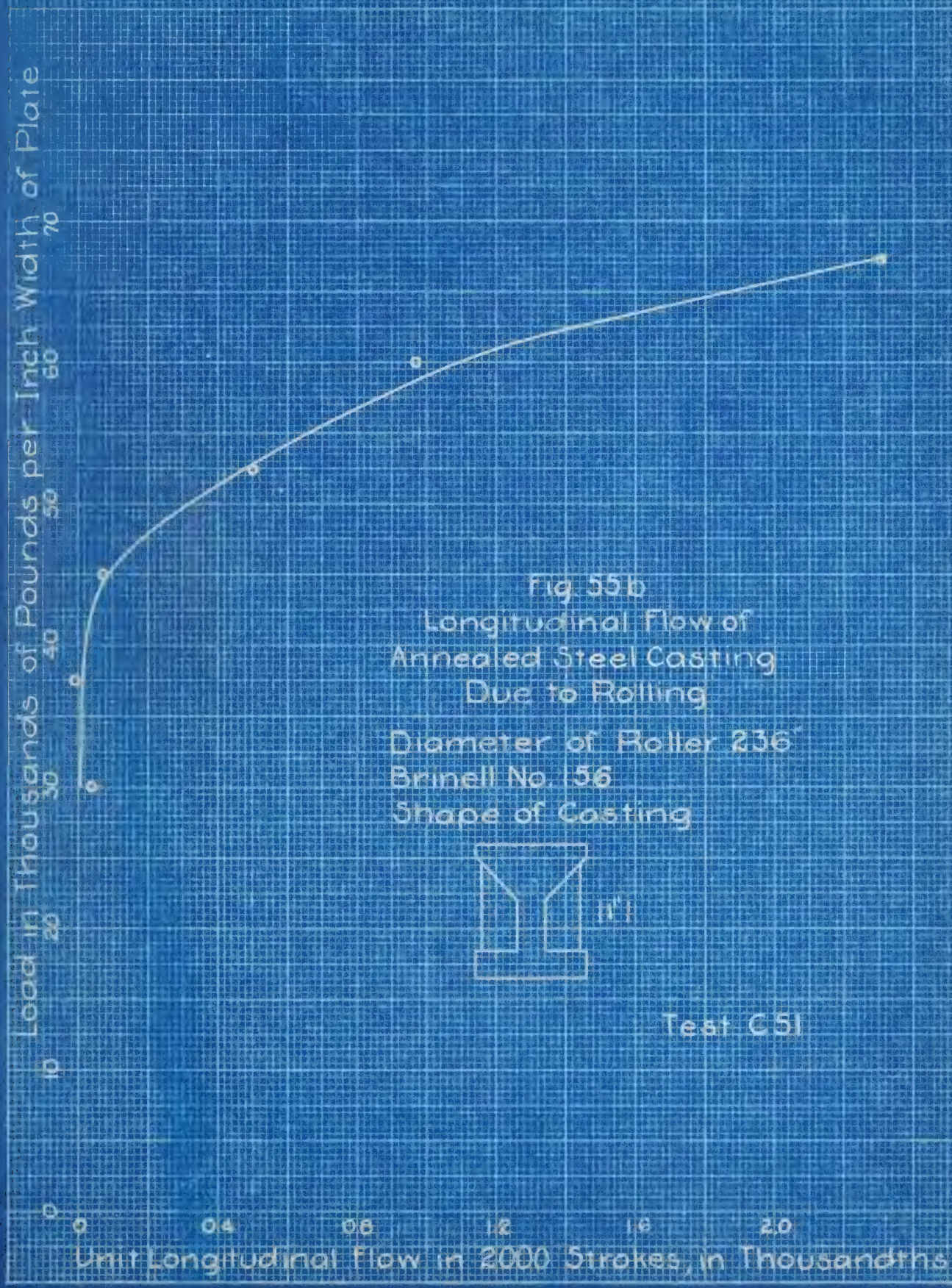
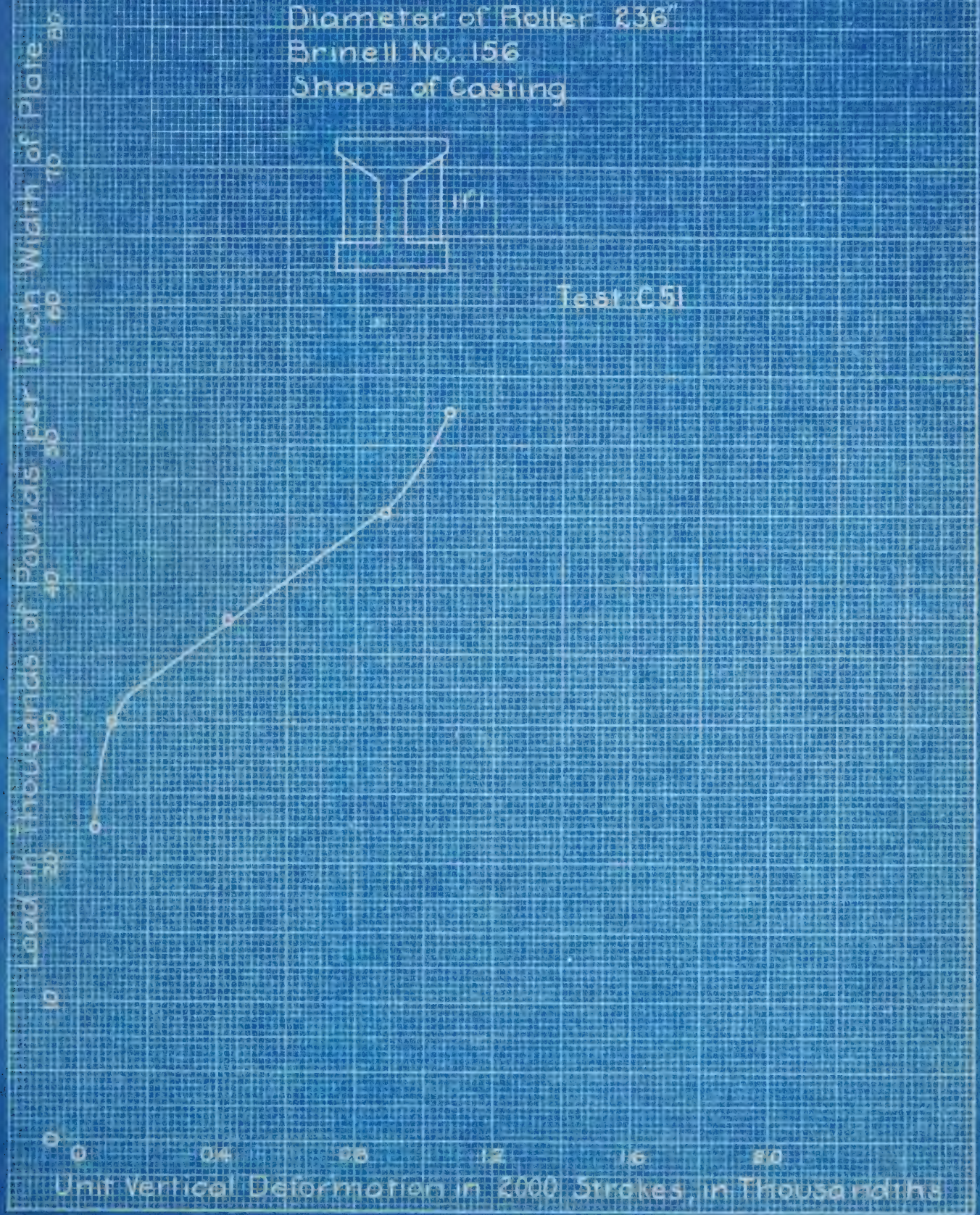

Load in Thousands of Pounds per Inch Width of Plate
0
10
20
30
40
50
60
70
0
0.4
0.8
1.2
1.6
2.0
Unit Longitudinal Flow in 2000 Strokes, in Thousandths
Fig. 55b
Longitudinal Flow of
Annealed Steel Casting
Due to Rolling
Diameter of Roller 2.36"
Brinell No. 156
Shape of Casting
Test C51

Fig. 55c
Vertical Deformation in
Annealed Steel Casting
Due to Rolling

Diameter of Roller 2.36"
Brinell No. 156
Shape of Casting

Tear C 51



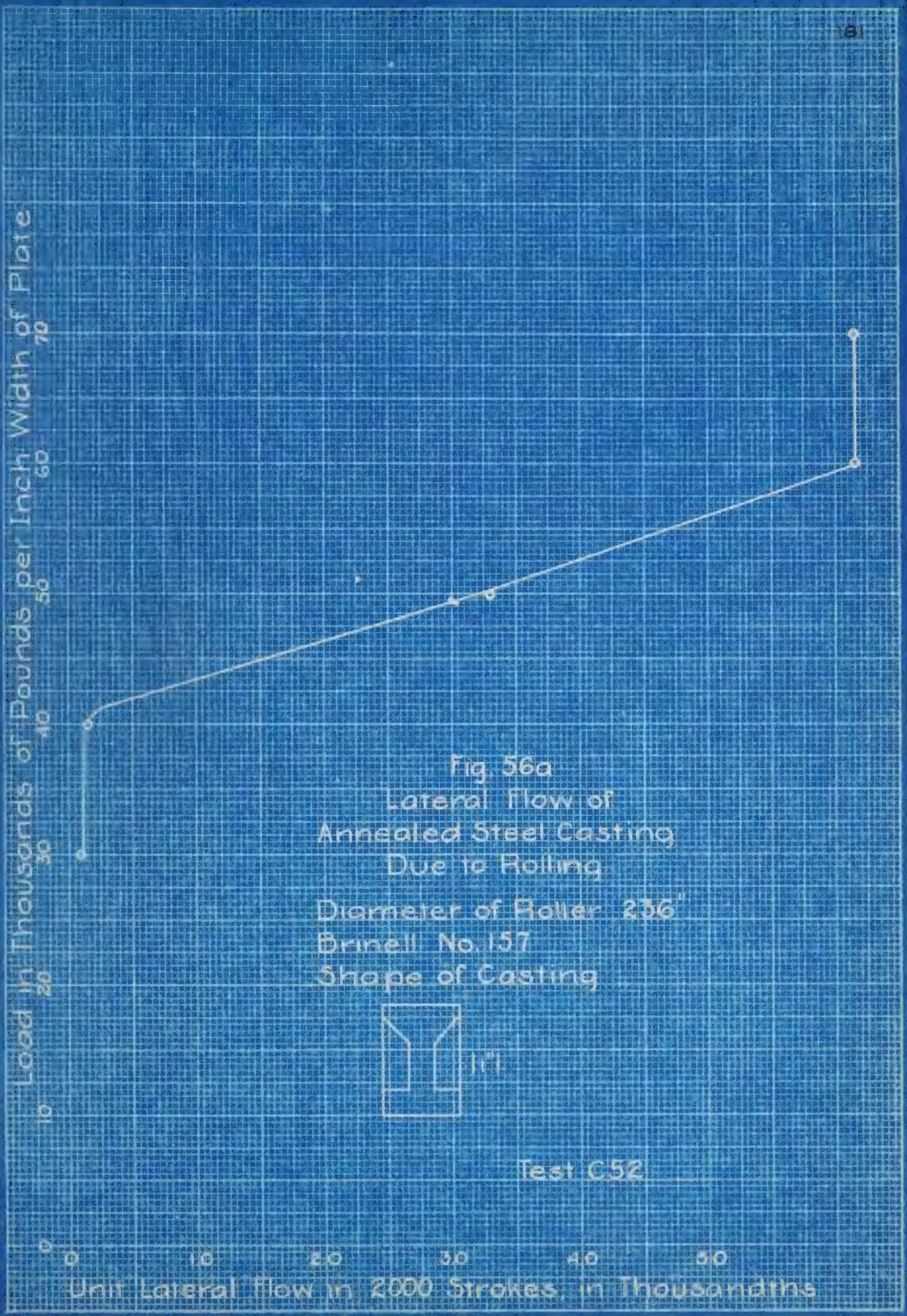


Fig. 56a
Lateral Flow of
Annealed Steel Casting
Due to Rolling
Diameter of Roller 2.56"
Brinell No. 157
Shape of Casting

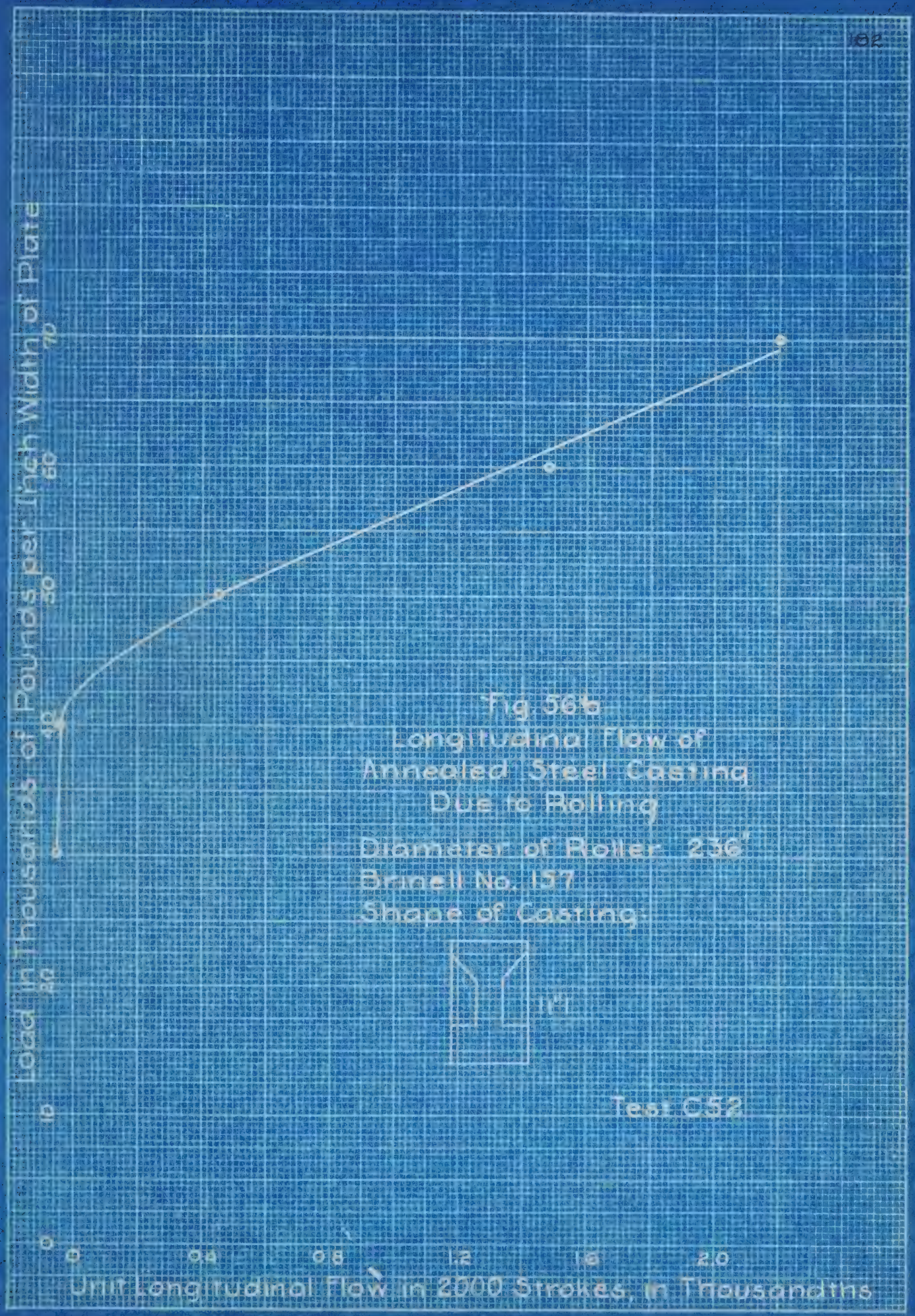
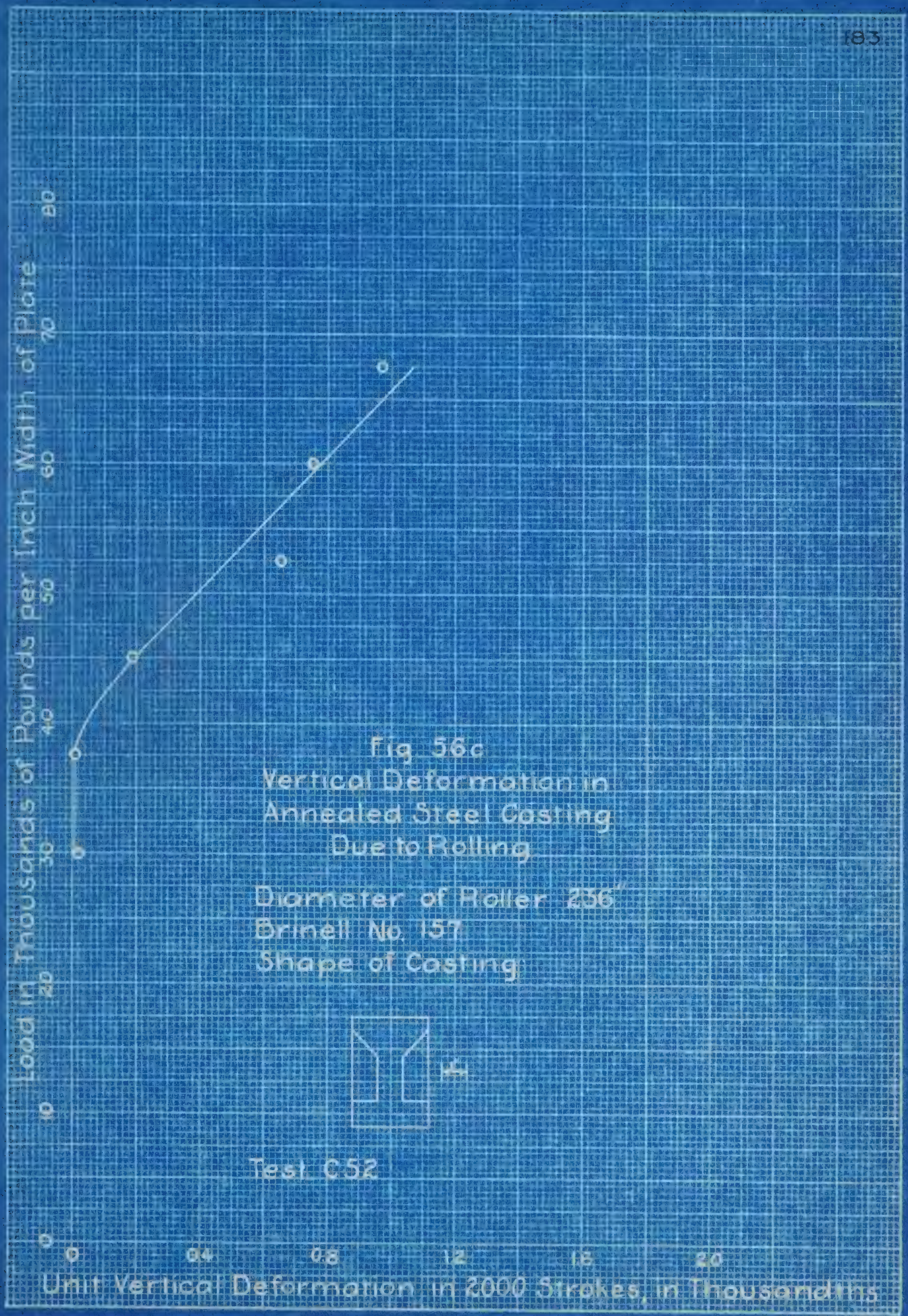


Fig. 56b
Longitudinal Flow of
Annealed Steel Casting
Due to Rolling
Diameter of Roller 236
Brinell No. 137
Shape of Casting
Test C52
Load in Thousands of Pounds per Inch Width of Plate
0
10
20
30
40
50
60
70
0
0.4
0.8
1.2
1.6
2.0
Unit Longitudinal Flow in 2000 Strokes in Thousandths


Load in Thousands of Pounds per Inch Width of Plate
0
10
20
30
40
50
60
70
80
Fig. 56c
Vertical Deformation in
Annealed Steel Casting
Due to Rolling
Diameter of Roller 2.56"
Brinell No. 157
Shape of Casting
Test C52
0
0.4
0.8
1.2
1.6
2.0
Unit Vertical Deformation in 2000 Strokes, in Thousandths

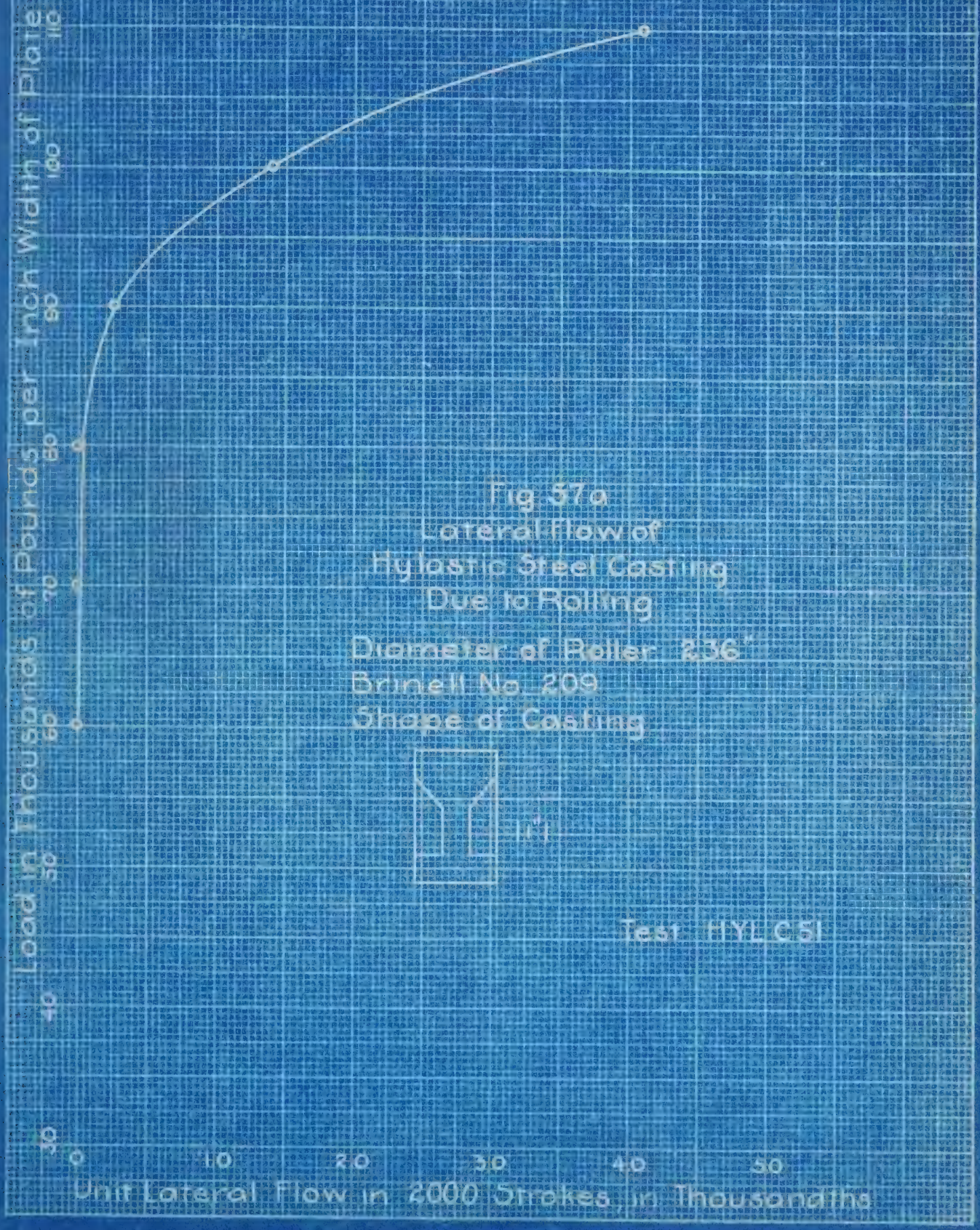


Fig 57a
Lateral Flow of
Hylastic Steel Casting
Due to Rolling

Diameter of Roller 2.36"
Brinell No 209
Shape of Casting

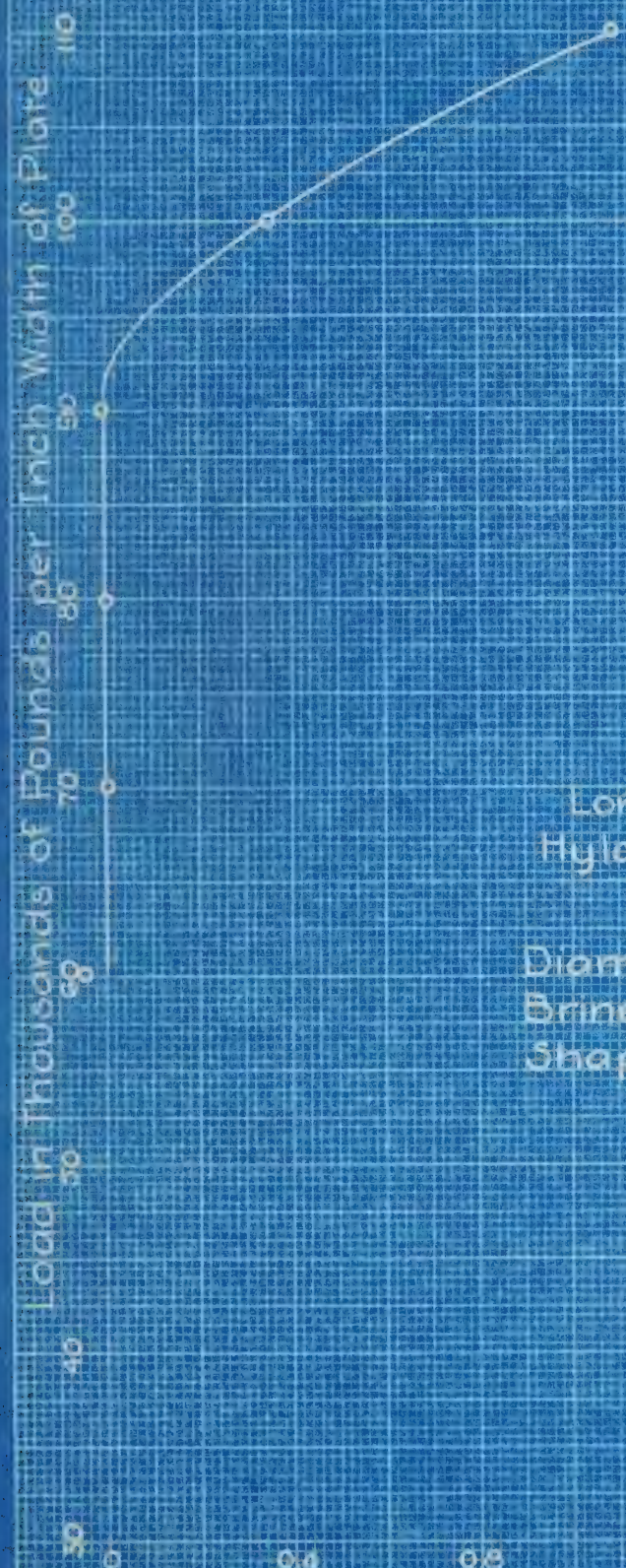


Fig. 37b
Longitudinal Flow of
Hylastic Steel Casting
Due to Rolling

Diameter of Rolling 2.36"
Brinell No. 209
Shape of Casting

Test HYL C 51

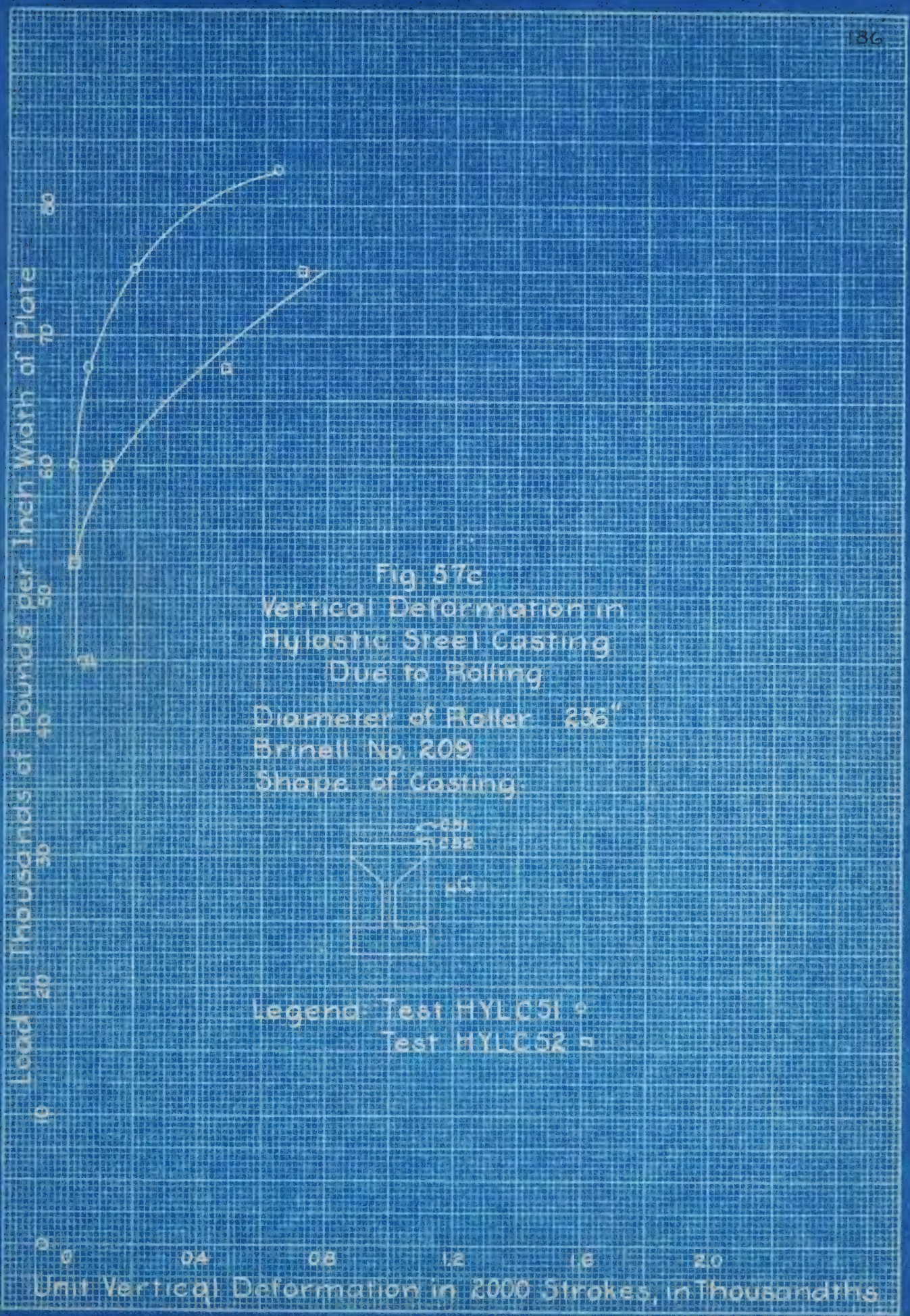
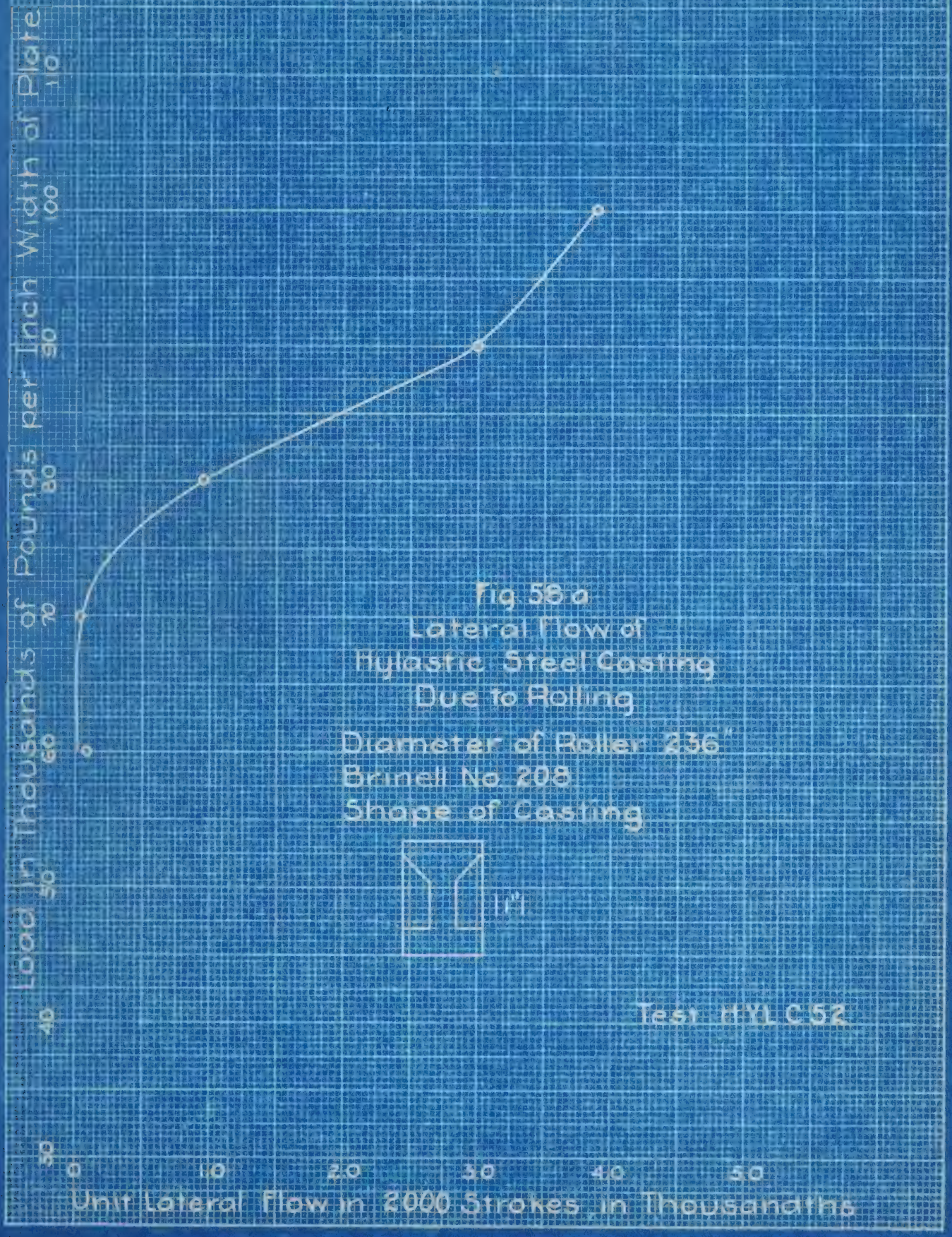


Fig. 57e
Vertical Deformation in
Hylastic Steel Casting
Due to Rolling

Diameter of Roller 256"
Brinell No. 209
Shape of Casting


Load in Thousands of Pounds per Inch Width of Plate
0
10
20
30
40
50
60
70
80
90
100
110
Unit Lateral Flow in 2000 Strokes in Thousandths
0
10
20
30
40
50
Fig 56a
Lateral Flow of
Hylastic Steel Casting
Due to Rolling
Diameter of Roller: 2.36"
Brinell No. 208
Shape of Casting
11"
Test HYLC 52

Load in Thousands of Pounds per Inch Width of Plate
30
40
50
60
70
80
90
100
110
0
0.4
0.8
1.2
1.6
2.0
Unit Longitudinal Flow in 2000 Strokes in Thousandths
Fig 58 b
Longitudinal Flow of
Hylastic Steel Casting
Due to Rolling
Diameter of Roller 2.36"
Brinell No 208
Shape of Casting
Test HYLC 62

FIG. 59

TESTS C 51

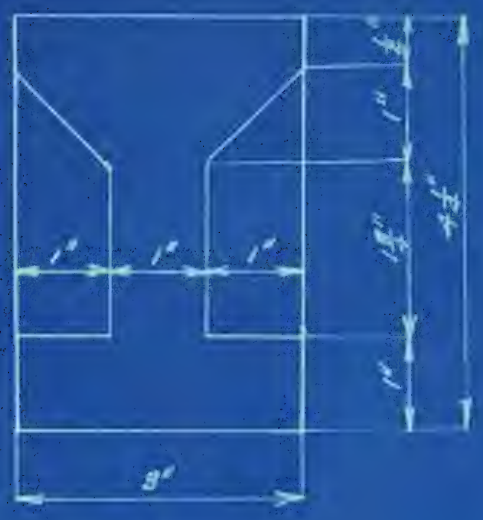
MATERIAL – CARBON STEEL CASTING
YIELD POINT – 43,500 LBS. PER SQ. IN
CRITICAL LOAD
LATERAL FLOW – 43,000 LBS. PER IN. WIDTH OF PLATE
LONGITUDINAL FLOW – 42,500 "
VERTICAL FLOW – 31,000 "

UNIT VERTICAL PRESSURE

DEPTH	PRESSURE
0	28,600
0.5"	19,600
1.0"	19,800
1.5"	24,000
2.0"	40,200
2.5"	34,600

FIG. 60

TESTS C52



MATERIAL - CARBON STEEL CASTING
YIELD POINT - 43,500
CRITICAL LOAD
LATERAL FLOW - 44,000 LBS. PER IN. WIDTH OF PLATE
LONGITUDINAL FLOW - 40,000 "
VERTICAL FLOW - 39,000 "

UNIT VERTICAL PRESSURE

DEPTH	PRESSURE
0	32,000
05"	22,600
10"	26,400
15"	43,000
20"	36,400
25"	

FIG. 81

TESTS HYL C51

MATERIAL - HYLASTIC STEEL CASTING
YIELD POINT - 57,700
CRITICAL LOAD
LATERAL FLOW - 90,000 LBS. PER IN. WIDTH OF PLATE
LONGITUDINAL FLOW - 95,000 "
VERTICAL FLOW - 70,000 "

UNIT VERTICAL PRESSURE

DEPTH	PRESSURE
0	42,100
0.5"	32,900
1.0"	26,700
1.5"	33,600
2.0"	58,000
2.5"	51,000

FIG. 62

TESTS HYL C52

MATERIAL - HYLASTIC STEEL CASTING
YIELD POINT - 57,700 LBS. PER SQ. IN.
CRITICAL LOAD
LATERAL FLOW - 75,000 LBS. PER IN. WIDTH OF PLATE
LONGITUDINAL FLOW - 75,000 "
VERTICAL FLOW - 57,000 "

UNIT VERTICAL PRESSURE

DEPTH	PRESSURE
0	36,800
0.5"	28,900
1.0"	34,600
1.5"	57,300
2.0"	49,200
2.5"	

C61, C62, HYL C61 and HYL C62. The shape and dimensions were the same in all these specimens and are shown in Figure 48. The load-deformation curves are given in Figures 63 to 66. The critical loads are as follows:

Specimen	Lateral Flow	Longitudinal Flow	Vertical Flow
C61	37500	38500	37500
C62	37500	37500	37500
HYL C61	67500	63500	61000
HYL C62	67500	66000	61000

Figures 67 and 68 show the stress at different depths in the plates on the foregoing assumption of stress distribution.

The yield point of the material in C61 and C62 is 43,500 pounds per square inch and that of HYL C61 and HYL C62 is 57,660 pounds per square inch. The calculated stresses indicate that the material is over stressed.

The effect of the stiffeners seems to be detrimental. The total load carried by C61 at critical load from vertical deformation was 150,000 pounds while C51 carried only 124,000 pounds.

The critical load from vertical flow of C61 and C62 is 37,500 pounds per inch width of plate which is about [illegible].6 of the critical load from vertical flow of C31 which has a solid rectangular section.

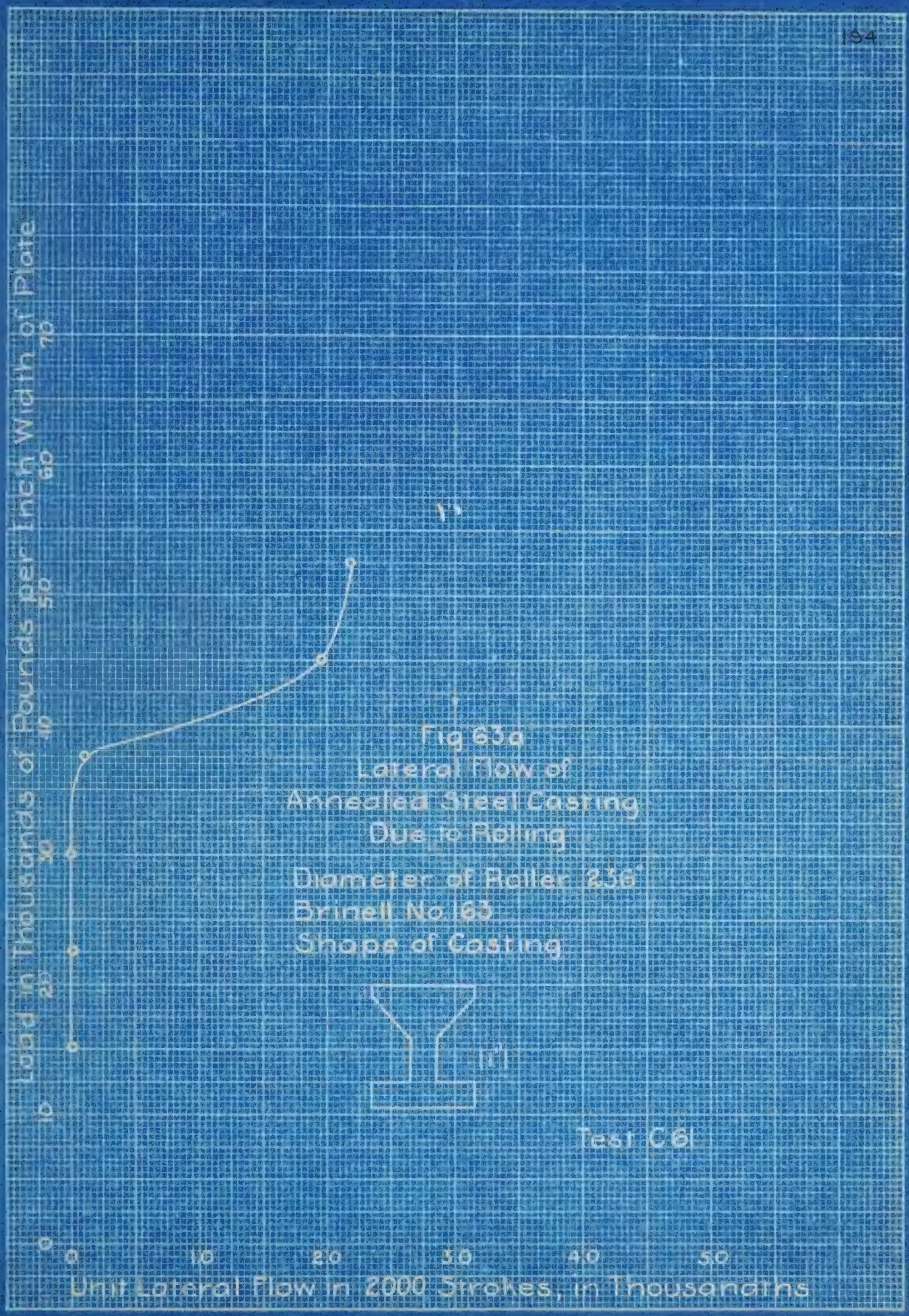


Fig 63a
Lateral Flow of
Annealed Steel Casting
Due to Rolling
Diameter of Roller 2.56"
Brinell No 163
Shape of Casting

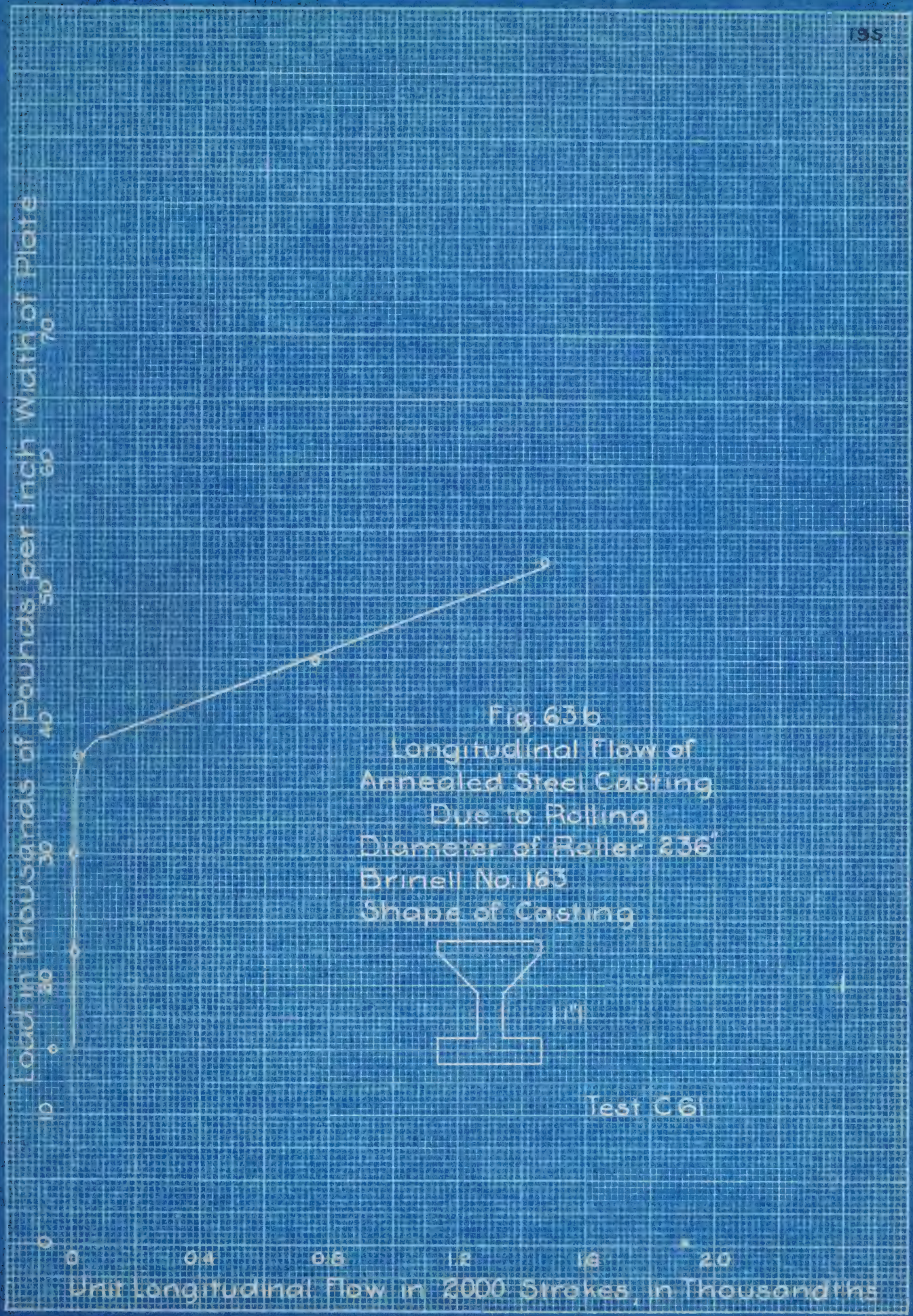
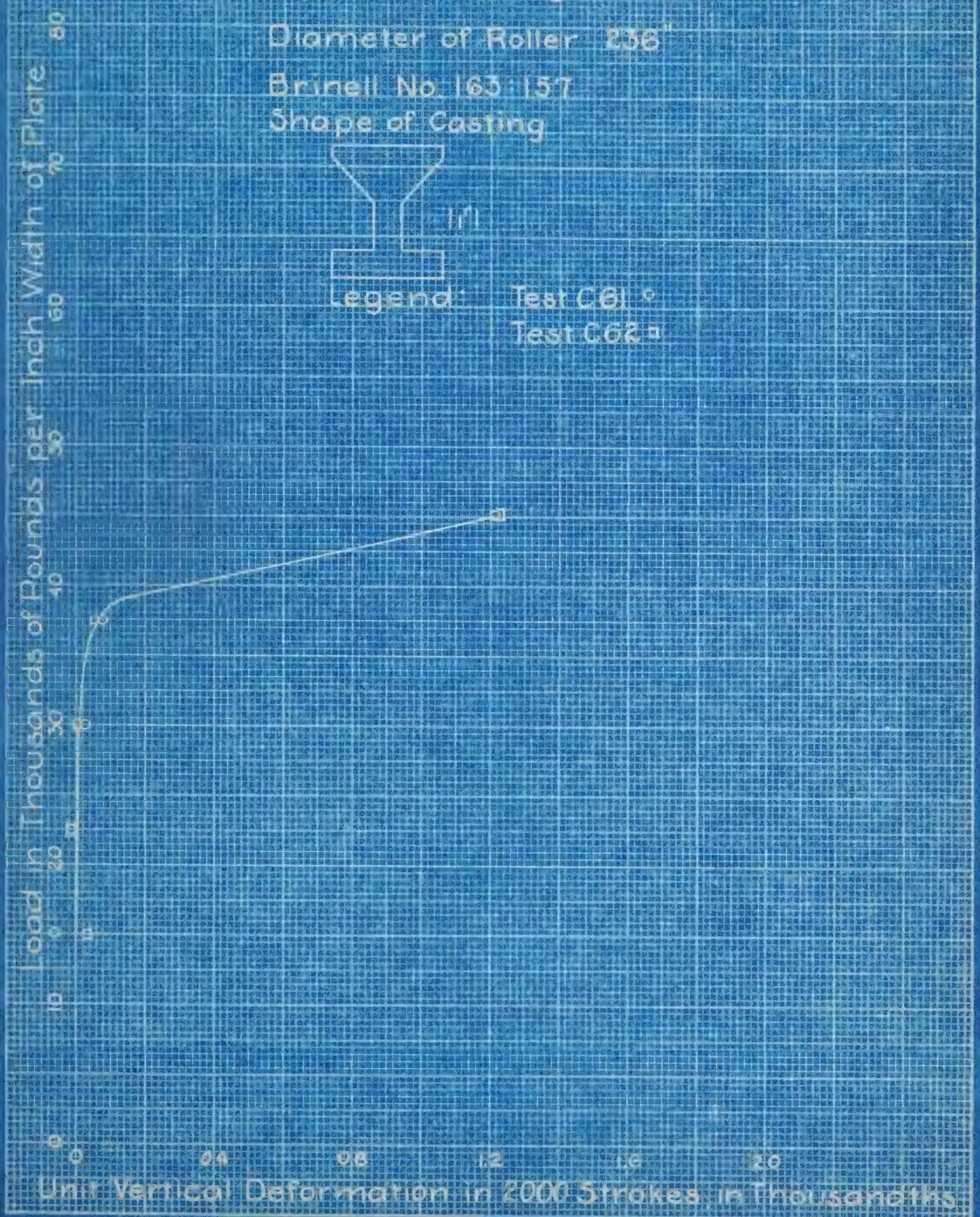

Load in Thousands of Pounds per Inch Width of Plate
0
10
20
30
40
50
60
70
0
0.4
0.8
1.2
1.6
2.0
Unit Longitudinal Flow in 2000 Strokes, in Thousandths
Fig. 63b
Longitudinal Flow of
Annealed Steel Casting
Due to Rolling
Diameter of Roller 2.36"
Brinell No. 163
Shape of Casting
Test C61

Fig. 65c
Vertical Deformation in
Annealed Steel Casting
Due to Rolling

Diameter of Roller 8.56"

Brinell No. 163-157
Shape of Casting

Legend: Test C61 ○
Test C62 □



Load in Thousands of Pounds per Inch Width of Plate
0
10
20
30
40
50
60
70
0
.8
1.6
2.0
3.0
4.0
5.0
Unit Lateral Flow in 2000 Strokes in Thousandths
Fig 64a
Lateral Flow of
Annealed Steel Casting
Due to Rolling
Diameter of Roller 256
Brinell No 137
Shape of Casting
16"
Test C82

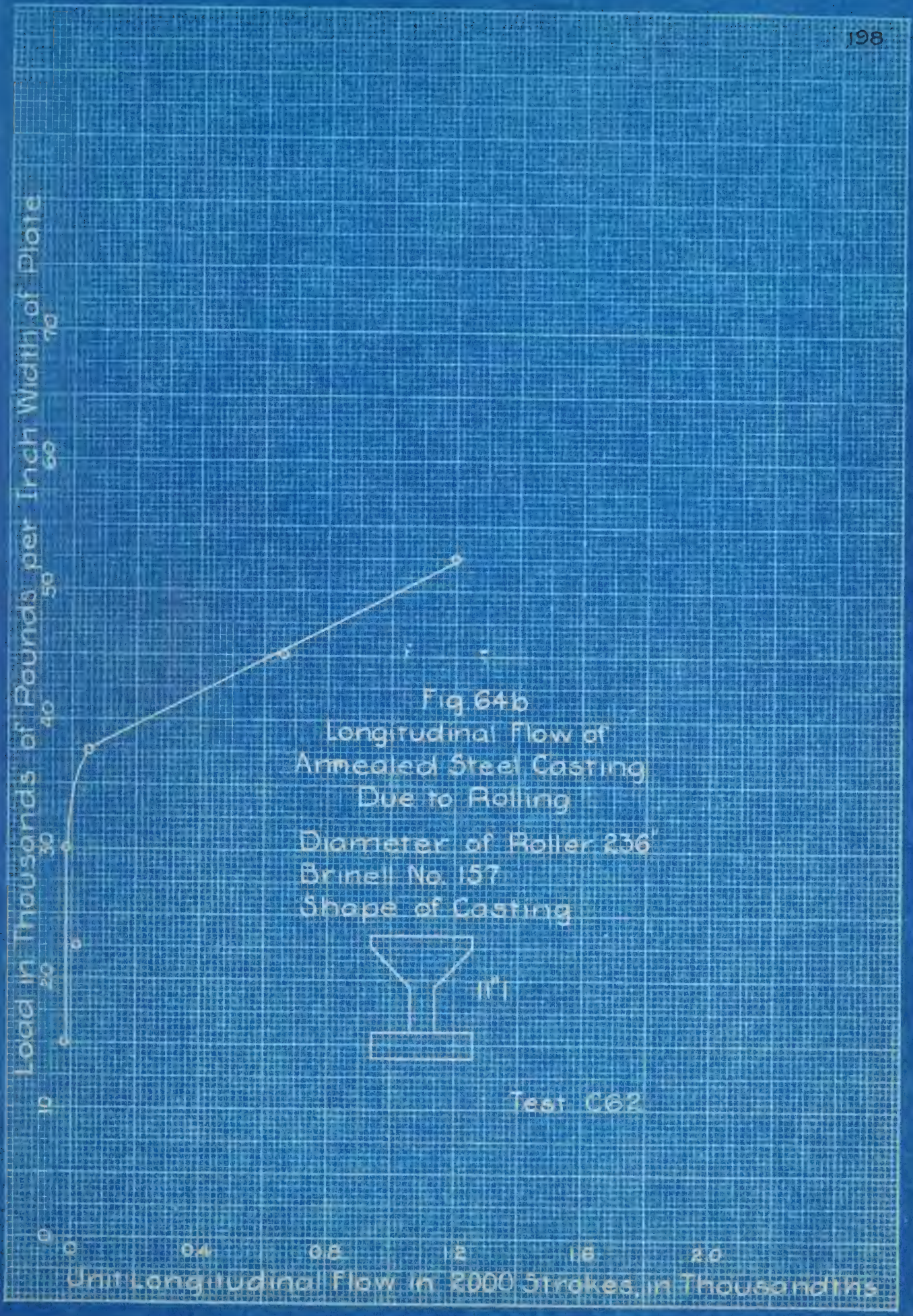


Fig. 64b
Longitudinal Flow of
Annealed Steel Casting
Due to Rolling
Diameter of Roller 2.36"
Brinell No. 157
Shape of Casting

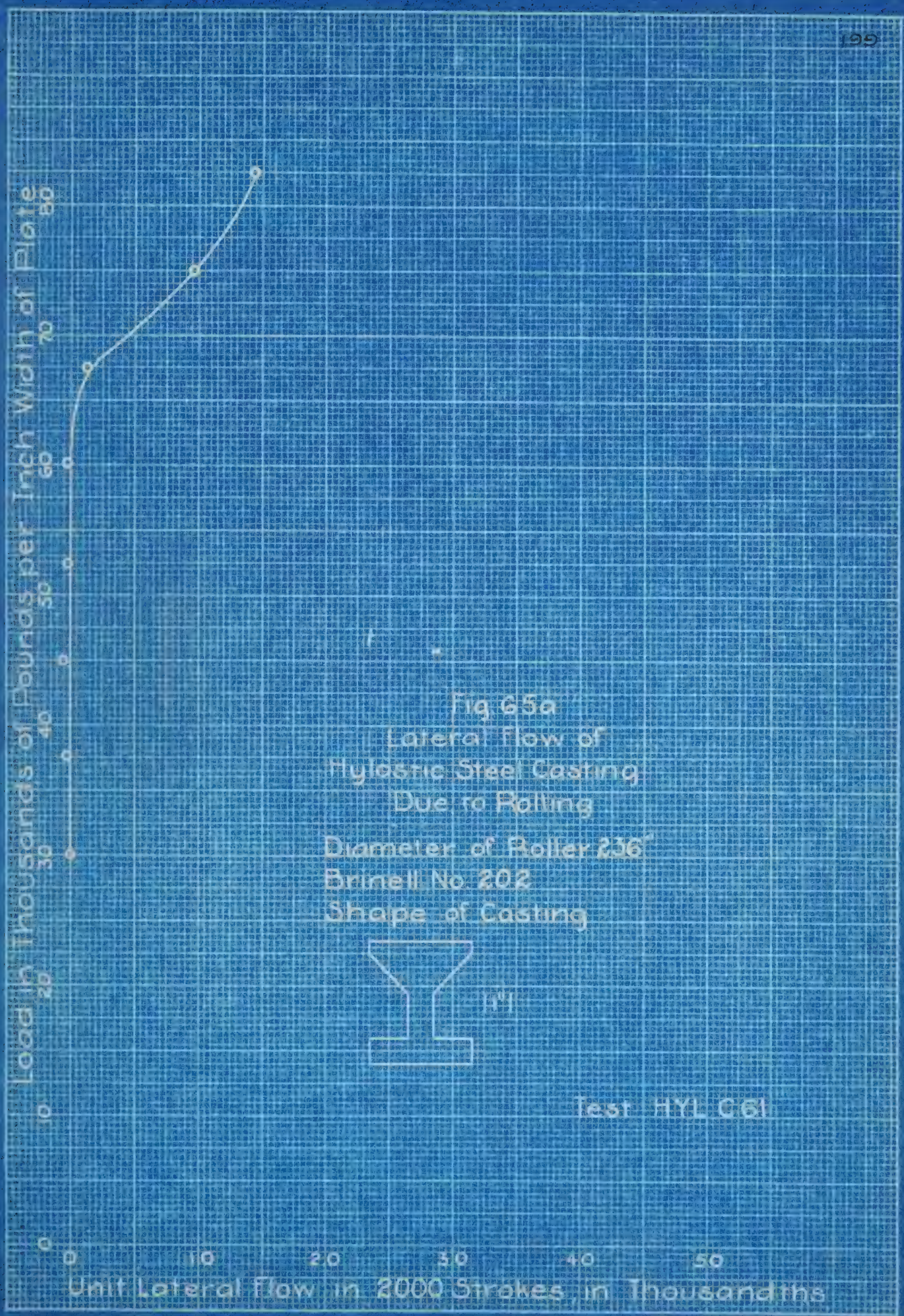
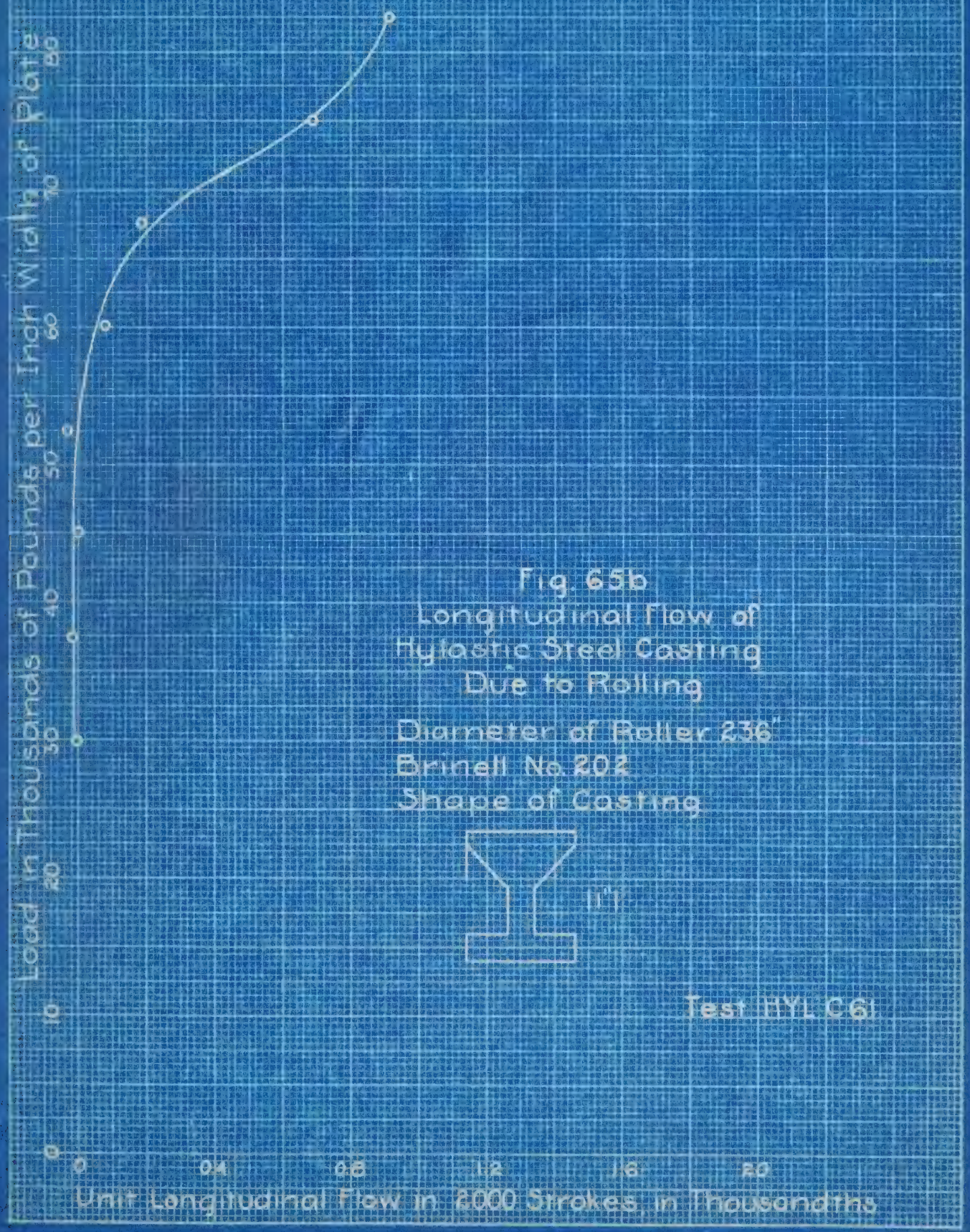
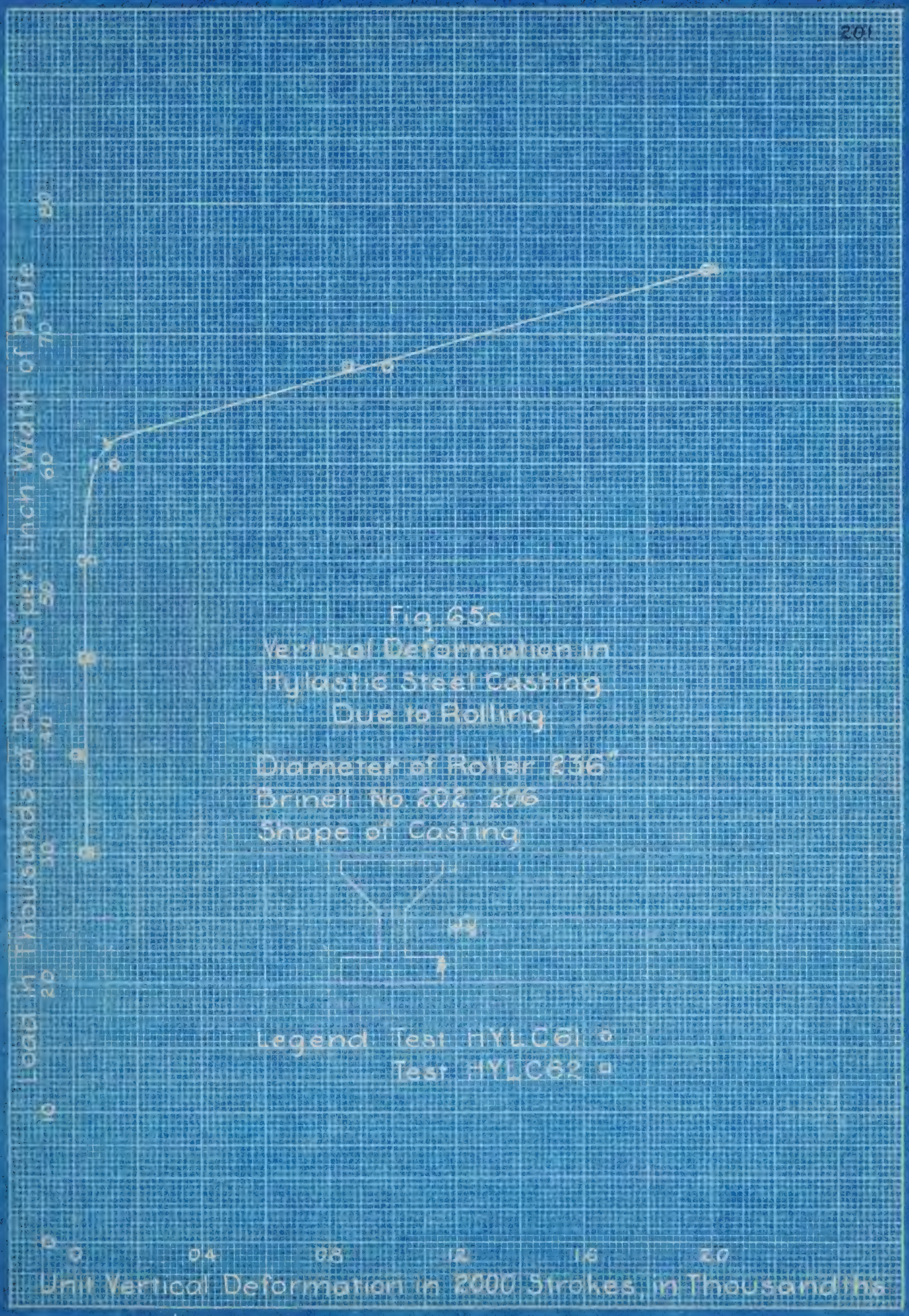


Fig. C 5a
Lateral Flow of
Hylastic Steel Casting
Due to Rolling
Diameter of Roller 2.56"
Brinell No. 202
Shape of Casting


Load in Thousands of Pounds per Inch Width of Plate
0
10
20
30
40
50
60
70
80
90
.04
.08
.12
.16
.20
Unit Longitudinal Flow in 2000 Strokes in Thousandths
Fig. 65b
Longitudinal Flow of
Hylastic Steel Casting
Due to Rolling
Diameter of Roller 2.36"
Brinell No. 202
Shape of Casting
Test HYL C61


Load in Thousands of Pounds per Inch Width of Plate
0
10
20
30
40
50
60
70
80
90
0
0.4
0.8
1.2
1.6
2.0
Unit Vertical Deformation in 2000 Strokes, in Thousandths
Fig. 65c
Vertical Deformations in
Hylastic Steel Casting
Due to Rolling
Diameter of Roller 2.06"
Brinell No. 202-206
Shape of Casting
Legend Test HYLC61
Test HYLC62

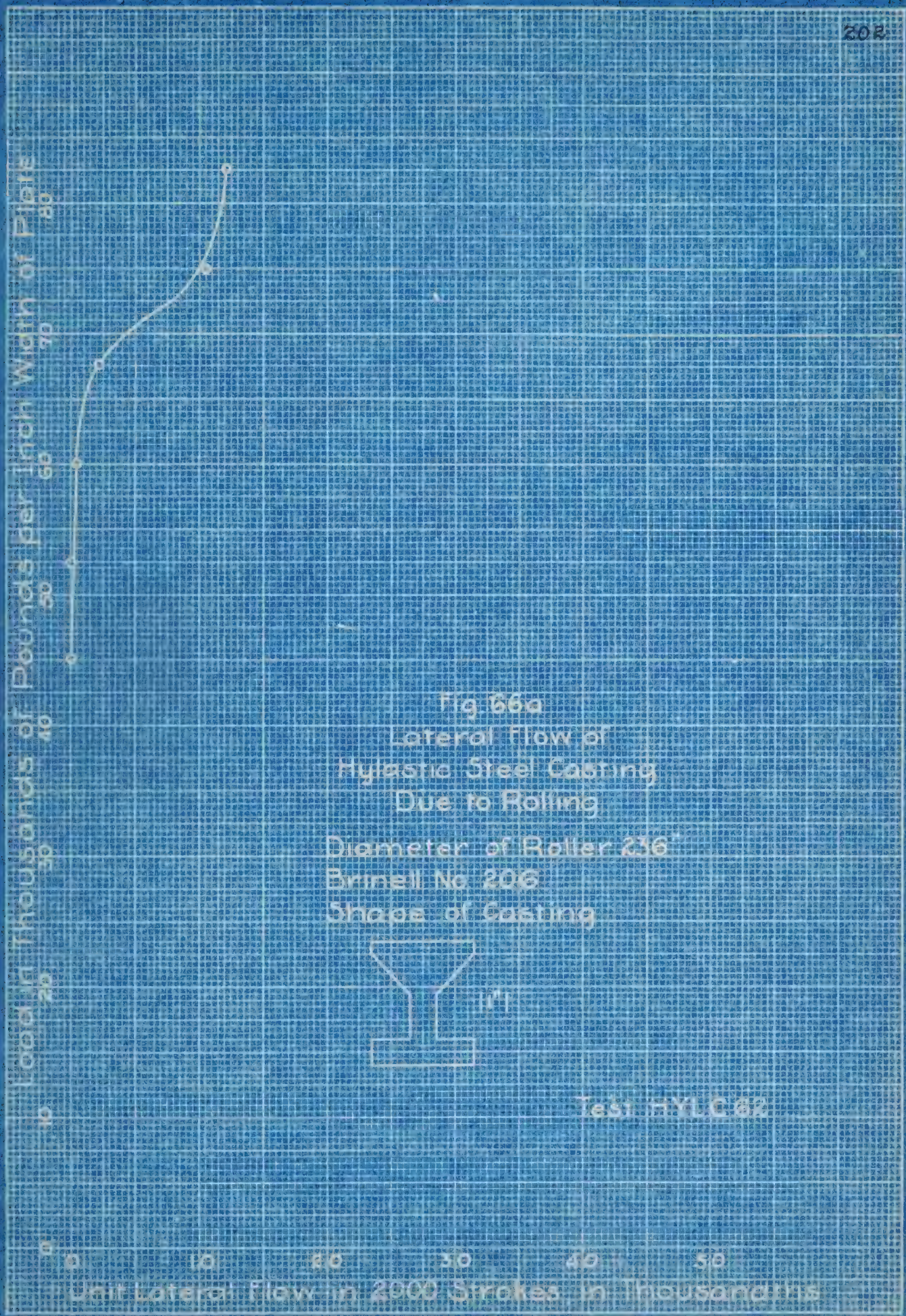


Fig 66a
Lateral Flow of
Hydraulic Steel Casting
Due to Rolling
Diameter of Roller 236
Brinell No. 206
Shape of Casting
Test MY-C67
Lateral Flow in 2000 Strokes in Thousand Lbs

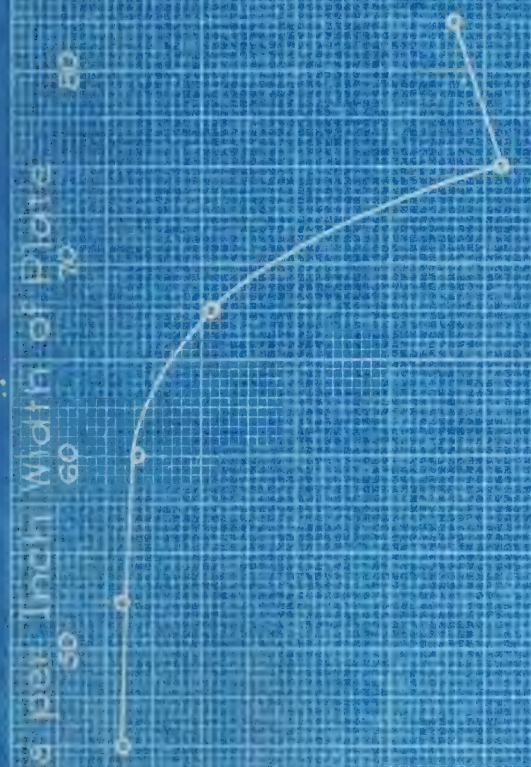


Fig. 66b
Longitudinal Flow of
Hylastic Steel Casting
Due to Rolling

Diameter of Roller 2.36"
Brinell No. 206
Shape of Casting

Test HYL C62

FIG. 67

TESTS C61 AND C62

MATERIAL - CARBON STEEL CASTING
YIELD POINT - 43,500 LBS. PER SQ. IN.
CRITICAL LOAD
LATERAL FLOW — 37,500 LBS. PER IN. WIDTH OF PLATE
LONGITUDINAL FLOW — " "
VERTICAL FLOW — " "

UNIT VERTICAL PRESSURE

DEPTH	PRESSURE
0	31,300
0.5"	22,000
1.0"	27,800
1.5"	27,800
2.0"	41,000
2.5"	40,500

FIG. 68

TESTS HYL C61 AND HYL C62

MATERIAL – HYLASTIC STEEL CASTING
YIELD POINT – 57,700 LBS. PER SQ. IN.
CRITICAL LOAD
LATERAL FLOW – 66,700 LBS. PER IN. WIDTH OF PLATE
LONGITUDINAL FLOW – 67,500 "
VERTICAL FLOW – 61,000 "

UNIT VERTICAL PRESSURE

DEPTH	PRESSURE
0	38,600
0.5"	29,300
1.0"	31,500
1.5"	38,600
2.0"	45,100
2.5"	54,800

APPENDIX

PHYSICAL PROPERTIES OF MATERIAL FOR SMALL ROLLER TESTS.

PHYSICAL PROPERTIES OF MATERIAL FOR SMALL ROLLER TESTS.

The physical properties of the small rollers are given in Table 7. They were determined by standard tension tests. Figure 69 shows the location of each specimen and the portion removed from the original block in making the rollers.

Table 1 is superceeded by Table 8. The values in Table 1 are the results of a single test while the values in Table 8 are the average of two duplicate tests.

Table 7 Physical Properties of Rollers
Bearing Value of Small Rollers.

Specimen		Ultimate	Yield	Reduction	Elongation	Brinell Number	
Roller	Location	Strength	Point	of Area	in 2 inches	Before	After
H1	S1	64 030	30 990	40.7	28.2	116	148
	S2	68 050	33 340	43.0	28.8		
	S4	66 450	34 630	42.0	28.5		
	S5	64 820	32 740	38.5	27.0		
	S6	68 820	32 110	44.3	25.6		
H2	S1	63 420	35 020	25.0	23.6	117	144
	S2	59 450	36 570	14.9	8.04		
	S4	55 180	37 750	19.0	8.8		
	S5	64 180	33 780	45.1	28.3		
H3	S1	57 270	32 110	20.08	9.5	128	148
	S2	60 550	34 390	19.78	18.00		
	S3	49 360	29 670	20.8	8.1		
	S4	60 300	34 340	10.6	9.5		
	S5	64 630	31 830	21.6	19.2		
	S6	65 680	30 600	36.6	26.2		
H3A	S1	61 170	31 480	22.9	14.6	133	151
	S2	62 930	31 810	12.77	7.2		
	S4	64 260	34 210	16.83	14.16		
	S5	55 760	32 350	17.24	8.25		
H5	S2	35 466	35 466	—	—	128	133
	S5	61 560	33 760	9.98	7.5		
	S3	43 480	30 990	8.41	3.75		
	S4	65 530	34 320	27.65	22.25		
H5A	S1	46 810	30 260	14.06	6.37	128	158
	S2	42 700	31 980	17.54	8.14		
	S4	62 440	32 570	26.21	16.75		
	S5	63 060	30 820	23.67	20.5		
	S6	62 980	31 470	27.04	24.0		
H7	S2	63 490	32 030	27.90	24.3	128	169
	S3	40 220	33 100	—	—		
H9	S1	23 650	23 650	—	—		
	S4	29 330	29 330	—	—		
	S5	63 400	33 860	38.54	22.5		
	S6	62 760	30 710	25.10	20.2		

Fig. 69
Diagram Showing Location of Specimens in Original Block

Table 8

Physical Properties of Plates

Bearing Value of Small Rollers

Specimen	Before Rolling					After Rolling				
	Ultimate Strength	Yield Point	Elongation in 2 inches	Reduction of Area	Brinell Number	Ultimate Strength	Yield Point	Elongation in 2 inches	Reduction of Area	Brinell Number
H1	64,720	32 690	30.6	41.1	128	65 900	36 650	25.7	34.8	147
H2	63 190	33 730	27.6	36.7	129	64 370	34 450	26.2	32.9	147
H3					141					159
H3A	64 500	31 880	27.2	36.4	128	65 020	34 640	27.9	39.8	151
H5					118					134
H5A	64 870	32 790	31.9	46.3	130	65 170	33 410	25.8	46.3	157
H7					128					165
H7A	64 120	32 590	28.2	38.6	132	63 750	32 760	26.3	32.3	185
H9	60 060	33 140	18.3	31.4		44 730	31 680	5.3	19.7	
H11	53 200	31 590	17.8	20.9	130	64 570	35 110	23.0	28.4	139
H12	64 110	31 910	26.4	36.6	129	64 810	34 530	26.1	31.7	139
H13	63 520	31 970	21.7	27.7	125	64 110	32 650	25.4	36.7	136
H14	65 050	31 110	28.9	38.9	128	64 540	34 260	25.9	35.8	138

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